



Citation for published version:

Barnett, J & Weyman, A 2016, Communication Challenges Associated with the Expression of Uncertainty in the Plant Health Risk Register. University of Bath.

Publication date:
2016

Document Version
Peer reviewed version

[Link to publication](#)

University of Bath

General rights

Copyright and moral rights for the publications made accessible in the public portal are retained by the authors and/or other copyright owners and it is a condition of accessing publications that users recognise and abide by the legal requirements associated with these rights.

Take down policy

If you believe that this document breaches copyright please contact us providing details, and we will remove access to the work immediately and investigate your claim.

Communication challenges associated with the expression of uncertainty in the Plant Health Risk Register

Commissioned Technical Report to the Department for
Environment, Food and Rural Affairs (DEFRA)

Authors: **Julie Barnett and Andrew Weyman**
Department of Psychology, University of Bath

July 2016



Table of Contents

Executive Summary.....	4
1. Introduction.....	12
2. Background to the Plant Health Risk Register	15
The aim of the Plant Health Risk Register.....	16
Who are the users of the Plant Health Risk Register?	16
The structure of Risk Registers.....	16
The Plant Health Risk Register and Uncertainty.....	17
Options for characterising uncertainty in the PHRR	17
3. Uncertainty: boundaries, definitions and types.....	19
Boundaries of Uncertainty	20
Defining Uncertainty.....	22
Types of uncertainty	23
Uncertainties arising from risk assessment.....	23
Policy delivery uncertainties	25
4. Communicating uncertainty.....	26
A communication framework.....	27
The mandate to communicate uncertainty.....	29
What are the challenges of communicating uncertainty within the risk register?	31
5. Reasons for (expert) reservations about communicating uncertainty	32
The role of the media	35
How do the media report risk?	36
Journalistic practices	41
What are lay responses to reporting of risk and uncertainty?.....	43
Implications for communicating risk and uncertainty	44
6. What is the evidence about lay responses to uncertainty?	47
Uncertainty and perceptions of risk and trustworthiness	48
Types of uncertainty from a lay perspective	50
Layering - a strategy for effective communication?	54
7. What heuristics and biases affect the characterisation and interpretation of uncertainty and related decision making?.....	56
Recognised sources of decision bias.....	56

Heuristics - mental short cuts and rules of thumb.....	58
Availability bias.....	61
Anchoring and adjustment bias	64
Representativeness bias.....	66
Confirmation bias.....	67
Loss aversion bias	71
Time frame biases.....	72
Cultural biases.....	73
Group decision making bias	75
Framing effects and bias	79
Semantic framing.....	79
Deep Framing.....	81
Techniques for characterising stakeholder perspectives on risk and uncertainty	82
8. How are different presentations of uncertainty interpreted? Numbers, Numbers versus Words, Number and Words	87
Numerical characterisations of uncertainty	88
Verbal Characterisations of Uncertainty	91
Semantics in Risk Assessment	92
Apples Xs oranges	93
Inter-assessor concordance	95
Relating semantics to numbers.....	100
Prioritising risks and uncertainties.....	103
Use of Graphics to Represent Uncertainty.....	107
Kite diagrams, radar diagrams and Pedigree Charts.....	108
Representing probability distributions	111
Alternative graphics for representing risk and uncertainty.....	117
9. Consideration of alternative representations of uncertainty surrounding PHRR pest/disease ratings	123
Risk Register rating plus Uncertainty Proxy rating (all pests within the Register).....	125
Uncertainty Range Based on Monetised Impact.....	128
Uncertainty range for Risk Register score	130
References.....	133

INDEX OF TABLES

Table 1: Domains of uncertainty in risk assessment	24
Table 2 Examples of sources of uncertainty in policy delivery	26
Table 3: Media triggers - adapted from Department of Health (1999)	39
Table 4: Criteria of news selection around the reporting of risk and environmental issues	40
Table 5: Journalist perceptions as to how they report stories about hazards and risks	41
Table 6: Insights about communicating with the media about uncertainty from the Independent review of the UK response to the 2009 influenza pandemic	42
Table 7: Non-expert perspectives on sources of uncertainty.....	50
Table 8: Progressive disclosure - Source Kloprogge et al, 2007	55
Table 9: IPCC 2007 - Judgement of uncertainty scale.....	101
Table 10 Summary of Recommendations to IPCC on Communicating Uncertainty in Risk Assessments to Lay audiences Source Buddescu et al, 2009	106
Table 11: Relative strengths of PDF and CDF's	112
Table 12: Morgan & Henrion 1990 - Summary of findings.....	115
Table 13: Lipkus and Hollands 1999 - Key findings.....	119
Table 14: Typology of maps for representing uncertainty	122

INDEX OF FIGURES

Figure 1: Concentric Model of Communication	29
Figure 2: Characterisation of Mental Models approach for developing communication content on risk & uncertainty - after Morgan et al 1992.....	83
Figure 3: Characterisation of public perspectives on veterinary medicine risks	85
Figure 4: Relative Public Trust in Risk Management Stakeholders	105
Figure 5: Example NUSAP Radar and Kite diagrams.....	109
Figure 6: Example Radar Graph Source Risk Gauging Tool (Weyman and Bibby, 2005).....	110
Figure 7: Example IPCC pedigree chart.....	111
Figure 8: Alternative Representations of Probability - Ibrenk and Morgan 1987.....	114
Figure 9: Graphic representation of uncertainty proxy score	126
Figure 10: Graphic representation of range of uncertainty over monetised value of impacts	128
Figure 11: Graphic representation of range of uncertainty referenced to point estimates...	131

Executive Summary

Section 1: Introduction

The aim of this review was to identify communication challenges associated with the expression of uncertainty in the Plant Health Risk Register (PHRR) and inform future Defra strategies for addressing these challenges.

Our starting point is that the communication of uncertainty potentially relates to much more than issues of wording, numerical format and presentation. The effective communication of science and associated uncertainties, particularly for high profile / high consequence pests and diseases can require more than the application of tools and techniques that simplify and demystify complex phenomena.

First we describe the PHRR itself, its history and the aspirations for it as a risk management tool (Section 2). A working definition of uncertainty and an overview of its various manifestations follow in Section 3. We consider the reasons why uncertainty should be communicated, and suggest the particular challenges of doing so within the PHRR (Section 4). This leads to a consideration of the reasons that there might be for expert¹ risk-assessor reluctance to communicate uncertainty (Section 5) – which includes the evidence pertaining to media characterisations. Section 6 considers the way in which lay audiences might make sense of uncertainty. The next two sections move to what can be characterised as micro-level considerations, first considering evidence, largely from cognitive psychology, about the interplay between cognitive biases / recourse to heuristics and the characterisation of uncertainty that can impact on how risk is perceived and reacted to by stakeholders (Section 7) and second, broader social science insights on the accuracy of lay interpretations of alternative representations and characterisations of uncertainty (Section 8). In conclusion, in Section 9, we reflect on the main lessons to be drawn for the communication of uncertainty relating to the PHRR and, in particular, consider the implications of alternative formats for representing and characterising uncertainty in the PHRR.

Section 2: Background to the Plant Health Risk Register

Developing a PHRR was one of the key recommendations of the Tree Health and Plant Biosecurity Expert Task Force which reported in 2013. The PHRR aimed to provide a single repository for drawing together numerous risk assessments pertaining to individual pests and pathogens. As well as serving to prioritise risks, it was charged with '*enabling systematic and*

¹ Throughout this document the term 'expert' is used to refer to individuals with recognised expertise in assessing plant pests and diseases and their propagation.

proportionate risk management responses, including stakeholder engagement. In response to this recommendation the PHRR was developed.

The inputs to the overall UK Relative Risk Rating score ratings are subject to various forms of uncertainty. The way in which they are combined is also subject to uncertainty. How can these uncertainties best be recognised, captured and represented?

Three main options are explored:

1. An uncertainty range referenced to the Risk Register rating
2. An uncertainty range translated into monetised impacts
3. Risk Register supplemented by an uncertainty proxy rating derived from published findings and related scientific insights.

Section 3: Uncertainty: boundaries, definitions and types

It is recognised that relevant domains of uncertainty extend beyond the technical properties of pests and diseases and options over their mitigation/control. They extend to the social world, and include uncertainty over economic impacts; stakeholder reactions to threats; and, the capacity of g/Government and its institutions to influence the behaviour of others, notably in the areas of propagation of acceptance and adoption of mitigation measures.

Definitions of uncertainty and the distinction between risk and uncertainty are outlined.

Most particularly the distinction is made between uncertainty in risk assessment and policy delivery are outlined.

Headline findings

- A core challenge is to portray uncertainties in ways that are accessible to target audiences but which, at the same time, do not convey the impression that science in the area is fundamentally speculative offering no clear way forward.
- The boundaries of uncertainty are not limited to underpinning natural science insights and confidence in the results of risk assessment. Relevant domains of uncertainty extend beyond the technical properties of pests and diseases and options over their mitigation/control.
- Principal domains of uncertainty relate to the nature of threat posed by pests or diseases; magnitudes of impact; the intrinsic effectiveness of mitigation measures; rates of adoption of mitigation measures; stakeholder reactions to mitigation measures; stakeholder orientations to risk management institutions.
- Purist perspectives on risk assessment and risk management cast these as essentially separate processes. However, effective policy science rests upon their integration.

- Three dimensions of uncertainty- level (scientific to statistical); location (domains in which uncertainty can occur); nature (stochastic- inherent indeterminability).
- Recognising the features of risks and institutional reactions to them that are important to stakeholders should inform thinking over which uncertainties need to be addressed.

Section 4: Communicating uncertainty

A framework for considering the communication of uncertainty is presented and the mandate to communicate uncertainty is set out.

Headline findings

- There are three dimensions to communication - micro, process and macro.
- The focus of concern / need for information on uncertainty may vary between stakeholders.
- The focus of concern / need for information on uncertainty may vary as threats from pests or diseases and institutional reactions to them mature.
- There may be benefits from a layered approach to communicating uncertainties
- Identification of a single policy option may be inconsistent with acknowledgement of uncertainty and obscure a clear view of areas of agreement and disagreement and the reasons that lie behind these.
- One of the challenges associated with the communication of uncertainty in relation to a risk register is that the process for identifying uncertainties should be proportionate to the process for characterising the risk and congruent with the purpose of the risk register.
- Although it may not be acknowledged, the characterisation of risk and uncertainty is linked to values and preferences

Section 5: Reasons for expert reservations about communicating uncertainty

Reasons for expert concerns about communicating uncertainty are considered within the context of insights from the Social Amplification of Risk Framework. In particular, the role of the media in risk amplification is considered. Triggers to media coverage, criteria of news selection around the reporting of risk and environmental issues and journalist views as to how they report stories about risk are outlined. Evidence regarding the extent to which the media influence lay perception of risk and the implications for communicating risk and uncertainty are considered.

Headline findings

- Policy officials are sensitised to the scenario that the communication of uncertainty around tree disease may cause stakeholder concern and conflict that they believe are unwarranted.
- Distrust and reputational damage may result from obscuring uncertainty
- Given that many risks are not experienced directly, the media are key in re-presenting these

- The media are prone to report much more than technical estimates of risk and uncertainty. The way in which events are framed may highlight uncertainties that are not part of technical estimates – for example uncertainties about how the risk is being managed or regulated.
- A simple view that the media always sensationalise and exaggerate is not backed up by evidence, although scientific uncertainty may be depicted as a cause for concern through a focus on social aspects of uncertainty.
- The characteristics of risk that attract media attention are well established and the depiction of uncertainty around (e.g.) who is to blame, conflict, cover-up, what the implications are likely to further consolidate this attention
- An appreciation of journalistic practices will increase policy understandings of what is newsworthy and why and of the ways in which the story is likely to be covered

Section 6: What is the evidence about lay responses to uncertainty?

The mixed evidence around lay reactions to uncertainty and the impact of the presentation of uncertainty on estimates of, and concern about, the risk and on the trustworthiness of those communicating uncertainty is outlined.

Headline findings

- Denial of uncertainty is likely to signal a lack of honesty and accuracy and generate distrust. People do not expect certainty although they may dislike uncertainty.
- Uncertainty may increase perceptions of risk more for some hazards – e.g. those under societal rather than personal control.
- The communication of technical uncertainty may lead to attributions about the communicator and their risk management capabilities
- Lay publics tend to be concerned with a much broader range of uncertainties than experts are concerned about communicating
- The most unacceptable uncertainties tend to be those associated with government inaction rather than scientific processes
- People may infer uncertainty from conflicting perspectives
- A layering or stepped approach may help communicate uncertainty effectively.

Section 7: What heuristics and biases affect the characterisation and interpretation of uncertainty and related decision making?

This section provides an overview of the extensive literature on recognised sources of bias in decision making in the context of uncertainty. It draws heavily on insights from cognitive psychology, but it is informed and elaborated upon through reference to complementary insights from social psychology, sociology and social anthropology. This latter has the effect of broadening the perspective, beyond traits exhibited by all individuals (in varying degrees), to

elements that reflect social and cultural dispositional and process related influences on decision making in the context of uncertainty.

Headline findings

- People are disposed to use (heuristics²) when decisions are complex, time consuming or contain unknown / unknowable elements.
- High consequence outcomes tend to be viewed as more likely. People are prone to focus more on magnitude of outcomes than probability for catastrophic, large scale, irreversible risks.
- Vivid recall of past high consequence events can sponsor over estimate of the likelihood of their recurrence, or of analogous events occurring.
- Established beliefs about the nature and probability of harm can act as a filter on how new information is reviewed, e.g. hindsight bias.
- Unrealistic optimism bias has been identified as both an individual and a group phenomenon. Lack of real-world contextual insight, e.g. into working practices, may foster unreasonably optimistic beliefs surrounding the effectiveness of risk mitigation measures.
- Under most circumstances people are averse to loss. High uncertainty, makes people reluctant to invest even when potential rewards are high. People may become risk seekers when faced with a certain loss if they do nothing.
- The scope for large differences in individual expert risk assessments is high- group interaction or elicitation can increase consensus but may sponsor other undesirable effects. Group deliberative processes have potential to sponsor polarization and choice shift effects, as well as 'averaging effects', groups processes can lead to more extreme decisions (risk seeking or risk averse).
- Semantic framing of issues or options, e.g. as 'gains' of 'losses' can impact on perceptions and choices.

Section 8: How are different presentations of uncertainty interpreted?

The difficulty in finding effective ways to communicate uncertainty to lay audiences is not always appreciated in scientific, technical or policy communities. A variety of ways of characterising uncertainty have been developed, but most were created in scientific, technical or business contexts, essentially for internal use, such that not all are easily or appropriately interpreted by lay audiences. The evidence reviewed relates to what is known of lay understandings and interpretations of numbers, statistical concepts (e.g. probabilities, proportions, rates, percentages), and semantic characterisations and graphical representations of uncertainty.

² Simplified mental representations that focus on what the perceiver believes to be the most salient features of the presenting issue, routinely informed through inferential linkages to previously encountered patterns or relationships.

Headline findings

- It is safe to assume that almost all adults have a general intuitive awareness of chance, likelihood, dose-response relationships and trends.
- Lay audiences have been found to perform reasonably well in interpreting numerical probabilities attached to discrete events.
- Many people experience difficulty in comprehending the magnitude of low probability events, particularly when expressed as a decimal, e.g. .0001. *P* values will mean very little to most people. Probability density functions (PDFs) and Cumulative density functions (CDF's) are unfamiliar to laypeople and are conceptually unintuitive.
- There has been much interest in verbal (semantic) expressions of uncertainty in risk assessment and communication with lay audiences. Principal limitations relate to different interpretations of their meaning and establishing their relationship to numerical expressions of probability. The number and choice of semantic anchors used in some subjective judgement scales currently in use in the plant disease risk area do not appear to be closely aligned with recommendations on scale design. People (expert and lay) are prone to select more serious sounding words as expressions of probability that are 'contaminated' by a disposition to focus on the magnitude of potential consequences.
- Familiarity within scientific graphic representations of probabilities can sponsor an under-appreciation amongst experts of the difficulties laypeople may experience in interpreting them.
- Kite diagrams, radar diagrams and pedigree charts are used to express probabilities and uncertainties in other risk assessment/management domains. Box plots offer a simple intuitive format - and should represent a default choice within the limitations of this format. Risk maps offer an intuitive spatial display of risk and associated uncertainties. Types of map are characterisable as: difference maps, scenario maps, ensemble maps and grid maps.
- The area of graphics as a measure of uncertainty would benefit for further, more extensive and comprehensive, empirical investigation.

Section 9: Consideration of alternative representations of uncertainty surrounding PHRR pest/disease ratings

In the final section of the report the relative strengths and weaknesses of the three possible representations of uncertainty outlined in Section 2 are outlined

Headline conclusions

Risk Register Point Value plus Uncertainty Proxy Score (all pests in Register)

Strengths

- Effort to develop is proportionate to the aims of the Risk Register.
- Conveys an impression of objectivity through reference to underpinning science

- Stakeholder involvement in selecting proxy measures might enhance ownership and acceptance.

Weaknesses

- Assumes weight of knowledge diminishes uncertainty - the converse can also be the case.
- Risks underplaying unknown and unknowable unknowns
- Subject to publication bias; funding bias and time lags between empirical work and publication date
- Risks underplaying context, e.g. local conditions / practices
- Not directly related to the uncertainty around risk point estimates - may inadvertently lend more credence to the point estimates than is justifiable.

Uncertainty Range Based on Estimates of Monetised Impact

Strengths

- Reflects potentially strong alignment with decision making criteria applied within the policy domain, e.g. intervention choices and research investment
- May chime with interests of certain stakeholders

Weaknesses

- Labour intensive for retrospective application to all pests within the Risk Register - may be disproportionate / unnecessary for all pests.
- Assessment of monetised values requires expertise beyond plant-pest science.
- Explicit link between cost and priorities invites media attention.
- May sponsor debate over values and their bases
- Prone to sponsor public suspicion of partisan interests
- Calculation of externalities can be unintuitive to non-experts.
- Cost as a justification for non-intervention may arouse stakeholder concern.

Uncertainty range for Risk Register rating

Strengths

- Focus presents as being on scientific estimates of threat.

- Emphasis on natural science portrays as more neutral than when based on market costs.
- Direct relationship to point estimates.
- Good fit with expertise of assessors.

Weaknesses

- Labour intensive for retrospective application to all pests within the Risk Register - may be disproportionate / unnecessary for all pests.
- Post mitigation estimates will tend to be partial where assessor expertise is restricted to biological / technical domains - risk of underplaying wider considerations.
- Potential variability in references applied by assessors to the consideration of mitigated risk.

1. Introduction

The aim of this document is to identify communication challenges associated with the expression of uncertainty in the Plant Health Risk Register (PHRR) and inform future Defra strategies for addressing these challenges.

Plant pests and diseases embody the potential to impact on UK biological, animal and human systems in complex and uncertain ways. In common with other environmental challenges, a feature of plant pests and diseases is that early detection can be difficult, combined with high levels of uncertainty over their propagation and migration. This situation is further complicated by known and unknown interrelationships between variables, e.g. climatic conditions, the range of hosts and other transmission pathways. Such interactions can at times be complex and operate in subtle and adaptive ways, to the extent that future outcomes can be sensitive to small changes.

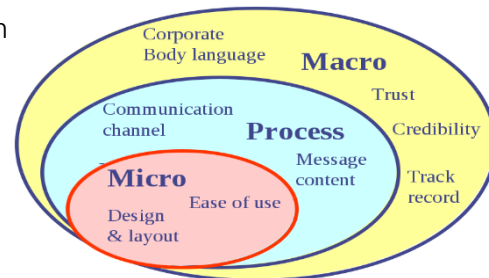
The ever increasing range and number of pests and diseases creates both opportunities and challenges for politicians, policy makers, scientists and other stakeholders to play a role in deciding over how to prioritise and combat these threats. In essence, the role of science in this is to provide evidence to support decision making, in at least four domains:

1. Horizon scanning - to identify the potential for harm.
2. Inform government and other stakeholders regarding the nature of arising threats.
3. Inform (principally) policy delivery decisions over actions which will prevent, or more routinely, mitigate the consequences of the pest or disease, and.
4. Provision of evidence relating to the effectiveness of mitigation measures.

Each of these processes embodies uncertainties that include: being able to recognise sources of harm; the characteristics / circumstances under which they will, or may, become manifest; the effectiveness of combined, or alternative, mitigation measures; and the propagation of their deployment. It is important to recognise that the application of science in this context embodies more than natural science expertise. By necessity, it must draw upon insights from risk management, social and communication sciences.

A key objective is to provide information and knowledge in a form that is accessible and actionable by decision makers and other stakeholders. Distilling what is routinely a large quantity of complex information into a form and format that is accessible to decision makers and other stakeholders is routinely challenging, particularly where levels of consensus and certainty may be limited. The scientist, in the role of communicator, needs to have clear insight into extant understandings (mental models), information needs (and objectives / preferences), cognitive capabilities and familiarity with scientific information of the target audience. It is important to recognise that this profile is prone to vary between different target audiences and with respect to the characteristics and impacts of different pest / diseases. Throughout this report the term 'lay' is used to refer to all target audiences that lie outside formal scientific and technical domains. This is not to deny that Government ministers, policy advisers, policy makers and other stakeholders do not possess relevant insight, rather it is based upon the premise that its presence cannot, and should not, be assumed.

The focus of this document is on the challenge of communicating uncertainty within the PHRR. Our starting point is that the communication of uncertainty potentially relates to much more than issues of wording, numerical format and presentation. Good communication practice embodies the capacity to present information in



formats that are accessible and provide lay audiences with the capacity to make well-judged decisions informed by scientific insight. This should not be interpreted as an elaboration of traditional perspectives on the communication of science as a one way process of 'seek and tell'. As will be articulated, in later sections of this review, the effective communication of science and associated uncertainties, particularly for high profile / high consequence pest and diseases can require more than the application of tools and techniques that simplify and demystify complex phenomena. A perspective that is restricted to this micro level where the focus is simply on finding inventive ways of translating complicated information into lay terminology is partial. Often more fundamental communication challenges lie beyond this, requiring thought to be given to the process of communication – what channels are being used to convey the information, what is the source of the information – and macro

considerations around trust, confidence, institutional accountability, and corporate body language of the communicator. These issues may subsume the micro challenges of communicating uncertainty, such that alternative formats for conveying uncertain information will be a largely irrelevant focus where, for example, questions of organisational accountability or blame become a key focus of attention.

The issue is complicated by the fact that communicator actions at one level can have implications for other levels. An example of such, pertinent to our current considerations, relates to the manner in which the risk analysis process – which would include the derivation and depiction of uncertainty estimates – has implications for trust and confidence in risk managers. Relatedly, as Frewer and Salter (2007) note when attempting to address public and stakeholder disquiet around risk issues (increasing the transparency of institutions and involving publics and stakeholders in policy development) there is a tendency to maintain a functional separation between risk assessment from risk management. In so doing, the risk analysis process is portrayed as *‘immune from values, preferences or investigation by different methodological variants’* and, hence, not open to question. In reality, in risk assessment, value and preference based choices that *are* made about, for example, which hazards should be the focus for action, or which unwanted consequences should be considered. Thus, assessments of risk and uncertainty are not simply the results of a scientific process (see too Jensen & Sandøe, 2002).

Frewer and Salter (2007) conclude that,

“The discounting of societal considerations as having any influence on risk assessment by institutions has become more problematic with increased transparency. This is because the (unacknowledged) application of values to risk assessment practices and processes become more obvious to citizens in general, but is systematically denied by other influential actors involved in risk analysis”

Having set the scene, this review will unfold as follows. First we will describe the Plant Health Risk register itself, its history and the institutional aspirations for it as a risk management tool (Section 2). A working definition of uncertainty and an overview of various types of

uncertainty will follow (Section 3). We will consider the reasons why uncertainty should be communicated, and suggest the particular challenges of doing so within the PHRR (Section 4). This will lead to a consideration of the reasons that there might be for expert reluctance to communicate uncertainty (Section 5) – which includes evidence pertaining to media presentations of uncertainty. Section 6 considers the way in which lay audiences might make sense of uncertainty. These sections, therefore, principally focus on the broader contexts for communication as depicted in the diagram above. The next two sections move to more micro-level considerations and first consider evidence, largely from cognitive psychology, about the heuristics and biases that affect the characterisation and interpretation of uncertainty and related decision making (Section 7) and second about the way in which different presentations of uncertainty are likely to be interpreted (Section 8). In conclusion, (Section 9) we will reflect on the main lessons to be learned for the communication of uncertainty in the PHRR and, in particular, will consider the implications for the potential formats for capturing and representing uncertainty in the PHRR. Throughout the report, in each Section, we have sought to distil the main points as a set of ‘Headline Findings’

2. Background to the Plant Health Risk Register

Developing a Plant Health Risk Register was one of the key recommendations of the Tree Health and Plant Biosecurity Expert Task Force which reported in 2013. The Task Force was set up in line with an ongoing commitment to addressing threats to tree health and biosecurity and an awareness of the heightened risk of transmission or importing disease from elsewhere in Europe, but was particularly triggered by the discovery in 2012 of *Chalara fraxinea* in native ash trees in the UK.

The remit of the Task Force when considering these issues was to “*make recommendations on how the UK should strengthen its responsiveness and preparedness in order to strengthen plant biosecurity and support tree health*” (p. 10).

One of the key recommendations of the Final Report of the Tree Health and Plant Biosecurity Expert Taskforce was the development of a prioritised Plant Health Risk Register (PHRR). The

stated purpose of this was to *“identify and prioritise the risks of those pests and pathogens that pose the greatest threat, including the probability of entry of exotics or the occurrence of new strains of indigenous species”*(p. 7) . Alongside this, a Chief Plant Health Officer was appointed, *“to own the UK Plant Health Risk Register and to provide strategic and tactical leadership for managing those risks”* (p. 5).

The aim of the Plant Health Risk Register

The PHRR was to form a single repository for drawing together risk assessments pertaining to individual pests and pathogens. As well as serving to prioritise risks it was charged with *‘enabling systematic and proportionate risk management responses’*, including stakeholder engagement. In response to this recommendation the Plant Health Risk Register was developed (Baker & Anderson 2014).

Who are the users of the Plant Health Risk Register?

The PHRR is publically available but the intended users and envisaged use are ‘government, industry and stakeholders’... ‘to prioritise action against pests and diseases which threaten our crops, trees, gardens and countryside’. Along similar lines, ‘it will (..) help a range of groups, including nurseries and woodland managers, to consider and manage risk effectively’.

The structure of Risk Registers

Risk Registers are a tool for risk management often used by companies and organisations (Breakwell, 2014). Typically, they delineate the risks associated with their main objectives and rate each of these in relation to their likelihood and impact. Multiplying these provides a ‘gross risk’ figure which has limited meaning insofar it can be derived from various combinations of impact and likelihood scores. Alongside this gross risk figure ‘improvement actions’ may be noted, along with the timescale for delivering these. The impact of the planned mitigating actions may be noted, thus giving rise to an estimate of the residual risk (remaining after mitigation has been effected) and there may be some indication of the acceptability of that risk.

To some extent, the Plant Health Risk Register is constructed along these lines although it is more complex, insofar as there are several dimensions underlying impact (social, economic and environmental impact) and likelihood (of both entry and establishment). Each of these dimensions and, in turn, the overall impact and likelihood are assigned a score of 1 – 5. There is also a rating of the ‘value of the host plants in the UK’ – similarly using a 1-5 scale. The UK Relative Risk Rating, which ranges from 1-125, - is derived by multiplying the impact x likelihood score with the value at risk score. There are two sets of these ratings – one representing the unmitigated risk and the other the mitigated risk³.

It is, thus, clear that this method of compiling the PHRR does not currently include any way of capturing the uncertainty that might exist about any of these judgements.

The Plant Health Risk Register and Uncertainty

In the course of developing the PHRR, the potential value of developing and testing approaches to capturing and expressing uncertainty was noted by the Expert Task Force; distinguishing uncertainties from ambiguities and ignorance in assessing risk (Stirling, 2014) and in stakeholder workshops. In the first phase of the PHRR uncertainties were noted in the form of free text. Work to develop and test more systematic approaches to capture and express uncertainty within the PHRR is ongoing⁴. This document is an adjunct to this, focusing, as it does, upon challenges that arise when communicating uncertainty⁵.

Options for characterising uncertainty in the PHRR

The options developed for characterising uncertainty⁹ are set in the context of an acknowledgement that the inputs to the overall UK Relative Risk Rating score ratings are subject to a range of domains of uncertainty. The way in which they are combined is also

³ For a full explanation of the composition of these ratings see <https://secure.fera.defra.gov.uk/phiw/riskRegister/Summary-of-Guidance-for-phase-1-Public-Ver2.pdf>

⁴ Fera project A2HE1000

⁵ A communication strategy for tree health issues has also been explored in a project on stakeholder mapping but this does not include a focus on the challenges of communicating uncertainty (Defra project TH0104)

subject to uncertainty. How can these uncertainties best be recognised, captured and represented?

An approach that has been suggested is to directly assess the uncertainty associated with each of the inputs. A variant of this is to translate the uncertainty estimates into quantifiable estimates of financial valuation of impact. A third, rather different approach is, not to reassess individual scores but rather, to seek to characterise how well known a pest is, and to use this as a proxy for the extent to which the characterisation of the pest in the PHRR is likely to be based on sound evidence.

The first of these alternatives could be achieved in several ways. One that has been suggested is to quantify the uncertainty of the risk ratings using the Direct Method. Under this method expert judgement is used to assign a probability to each point on the (1-5) scale rather than selecting a single value. The product of this is combined, with the output being a range or distribution. An alternative, the Holt method⁶, translates an expert rating of *high*, *medium* or *low* uncertainty into a set of probabilities, for each rating on each parameter. Given the size of the task, deriving uncertainty in relation to the 800+ plant diseases included in the PHRR, a further variation in characterising uncertainty for each of these approaches is introduced by rating more parameters early on in the process or fewer at a later point. Testing all four options (Direct Early, Direct Late and Holt Early and Holt Late) revealed differences required in analyst time and in the width of the distributions produced. A hybrid method was recommended for further consideration.

The third alternative – assigning proxy values indicative of the ‘known-ness’ of each disease can, in large part, be automated although some indicators (such as the number of references to the pest in a literature search of scientific databases require manual input. Early work focusing on a sample of 12 pest explored the relationship between the extent of uncertainty using the proxy method and the Direct Early method (above). This revealed a weak relationship and sponsored the conclusion that more work needs to be done to understand the reasons for this and its implications.

⁶ Named after the scientist who developed it

We now turn to addressing, more directly, the challenge of how to communicate uncertainty. In the next section, we consider the issue of representation of uncertainty with reference to the different domains of uncertainty.

3. Uncertainty: boundaries, definitions and types

"In contrast to general [scientific] practice, it is not enough to analyze uncertainty as a technical problem or merely seek for consensus interpretations of inconclusive evidence."

(van der Sluijs et al, 2008).

Headline findings

- *A core challenge is to portray uncertainties in ways that are accessible to target audiences but which, at the same time, do not convey the impression that science in the area is fundamentally speculative offering no clear way forward.*
- *The boundaries of uncertainty are not limited to underpinning natural science insights and confidence in the results of risk assessment. Relevant domains of uncertainty extend beyond the technical properties of pests and diseases and options over their mitigation/control.*
- *Principal domains of uncertainty relate to the nature of threat posed by pests or diseases; magnitudes of impact; the intrinsic effectiveness of mitigation measures; rates of adoption of mitigation measures; stakeholder reactions to mitigation measures; stakeholder orientations to risk management institutions.*
- *Purist perspectives on risk assessment and risk management cast these as essentially separate processes. However, effective policy science rests upon their integration.*
- *Three dimensions of uncertainty - level (scientific to statistical); location (domains in which uncertainty can occur); nature (stochastic - inherent indeterminability).*
- *Recognising the features of risks and institutional reactions to them that are important to stakeholders should inform thinking over which uncertainties need to be addressed.*

Boundaries of Uncertainty

Relevant domains of uncertainty extend beyond the technical properties of pests and diseases and options over their mitigation/control. They extend to the social world, and include uncertainty over economic impacts; stakeholder reactions to threats; and, the capacity of g/Government and its institutions to influence the behaviour of others, notably in the areas of propagation of acceptance and adoption of mitigation measures.

Increasing recognition of threats to society, combined with an increasing desire to manage and control sources of harm, and associated likelihoods, has sponsored an unprecedented focus on the capacity to predict and quantify impacts of the potential for harm, to the extent that there are accepted and recognised systems designed to quantify elements that were, in previous eras, regarded as unquantifiable (Power 2006).

"In the modern view of scientific policy advice, science produces objective, valid and reliable knowledge." (van der Sluijs et al (2008)).

The use of expert judgement has become a key component in this process. The widespread adoption of formal systems to identify and manage potential threats, based on theoretical analysis, is a relatively new phenomenon. It has been suggested that this anticipatory perspective should be more appropriately cast as *trans-scientific* (Weinberg, 1972) than scientific in the text book sense, due to the paradox that the most urgent public policy need for scientific evidence routinely occurs in areas in which evidence is least complete, lacking, or uncertain, i.e. it is characterised by problems that can be expressed in scientific terms, which established scientific method could, in theory, be used to address, but in practice are not amenable to empirical investigation (Otway and von Winterfeldt 1992). Of the published material that is available, a notable challenge with respect to its application is that it is rarely of close fit with policy needs, i.e. it was not configured to answer specific policy questions, such that in many instances there is a need to extrapolate from the general to the specific, in varying degrees. A proportion of residual uncertainty is resolvable through commissioning dedicated research, but frequently certain elements will remain unknowable. In some

instances, deep uncertainty may constitute the dominant characteristic.

"...in the real world...Scientific assessments of complex policy issues have to integrate information covering the entire spectrum from well-established scientific knowledge to educated guesses, preliminary models and tentative assumptions." (van der Sluijs. et al (2008).

The institutional reaction to this has been to openly acknowledge increasing reliance on expert judgement, while seeking to avert accusations of subjectivity and bias through publicly disclosing the nature of underpinning, ostensibly rigorous, formal procedures, suitably caveated through the articulation of sources and magnitudes of uncertainty. An observation might be that the procedures for assessment represent a closer approximation to traditional science practice than their product. This intense focus on procedural rigour mirrors contemporary public policy perspectives on the status of review evidence, notably the primacy ascribed to randomised control trials; an arising *risk* being that other knowledge may be overlooked or underplayed. Issues characterised by deep uncertainty are problematic from an evidence-based perspective.

Purist perspectives on risk assessment and risk management cast these as complementary but essentially separate processes (see, for example, EFSA, 2014). The rationale here is that risk assessment falls within the scientific and technical domain, whereas the latter, although informed by the former, reflects broader political, economic and social considerations, e.g. cost-benefit trade-offs and subjective judgements of tolerability (HSE 2001; van der Sluijs et al, 2008). However, experience has demonstrated that, when dealing with potentially high profile emotive sources of harm, a failure by risk assessors to recognise and take account of stakeholders' concerns can sponsor the development of quite different world views (Waage and Mumford, 2008). Recognising what is important to stakeholders is important with respect to the nature of information communicated on risk and uncertainty over threats, but also from the perspective of uncertainty amongst policy makers over reactions to proposed mitigation measures and rates of take-up (adoption), in instances where achieving control rests upon motivating behavioural change among stakeholders, e.g. land owners, producers, suppliers and importers.

Defining Uncertainty

“Uncertainty is essentially the absence of information, information that may or not be obtainable”

This definition makes it clear that uncertainty is not necessarily related to risk. Uncertainty is only about risk insofar as it is about negative outcomes or loss. Much early work on uncertainty was in the context of decision making, where there were possibilities of gain or loss. Here, though, we are dealing with the communication of uncertainty in the context of risk.

There are many definitions of uncertainty and similarly many more or less detailed ways of categorising the sources of uncertainty. The recent Government Chief Scientific Adviser’s annual report focused on risk in the context of innovation neatly locates uncertainty in relation to other relevant concepts (Government Office for Science, 2014). Thus, *risk* is a product of *hazard* and *exposure* to it (no exposure to a hazard equals no risk). Some people (or plants) may be more *vulnerable* through greater sensitivity to the hazard or greater exposure to it. *“Uncertainty is then concerned with the degree to which we are confident in our knowledge of hazard, exposure and vulnerability”* (p. 6)

The terms risk and uncertainty are not synonymous and explicit distinctions are made. Cook et al, for example, use risk to *“...designate situations where [the range of] possible outcomes and their probabilities are both known”*. Whereas uncertainty is cast as *“...situations when we know the possible outcomes, but not the probabilities of these outcomes.”* (Cook et al, 2012). However, as these authors go on to note, the concept of probability is integral to risk assessment, and essentially treated as a state that can be known, or at least judged. Citing Millner et al, (2010), Cook et al view this as problematic when dealing with unprecedented events, such as climate change and biological invasions. While this is true, and it represents a core challenge, it is not a unique feature of environmental issues, being no less true of the challenges surrounding assessment of the potential for catastrophic failure in complex engineering systems, e.g. power generation, mineral extraction, contexts in which the estimation of unknown quantities is treated as routine (see, for example, Turner et al, 2002;

2004).

There are however important differences in perspective and volition. Institutionally, the process of risk assessment in the major hazards sectors is essentially about mitigating the chances of failure to avoid injury to employees, the public, the environment and collateral losses, and convincing others that levels of control are suitable and sufficient. By contrast, environmental risk assessment might be characterised as the production of evidence to convince others that *we* are not in control, and action needs to be taken (see Power, 2006).

As alluded to at the beginning of this section, an important issue to acknowledge is that the boundaries of uncertainty are not limited to underpinning natural science insights and confidence in the results of risk assessment. Central to risk assessment is the concept of control. Specifically, measures that might be adopted to mitigate the consequences of the threat. Mitigation, under almost all circumstances, requires some level of action on the part of g/Government and its Agencies. In this context, notable uncertainty surrounds the impact of alternative courses of mitigation; associated costs and benefits; the capacity to propagate mitigation measures and the reactions of stakeholders to this endeavour. In the interests of clarity the following sections make a distinction between uncertainty in risk assessment arising from natural science insights and policy strategy / delivery uncertainties, e.g. capacity to manage stakeholder concerns; and capacity to propagate the adoption of mitigation measures.

Types of uncertainty

Uncertainties arising from risk assessment

In the context of formal risk assessment systems and conveying the results of such activity to stakeholders, the range of elements over which there may be a need to convey information on uncertainty can be extensive. Table 1 provides a list of domains of uncertainty cited in the literature (but should not be considered exhaustive).

Evidence informed public policy involves the translation of scientific and technical information

into forms and formats which are accessible to non-technical audiences. Even in instances where data is plentiful, where relationships are well understood with high levels of certainty, this can be challenging. More routinely, a range of uncertainties proliferate, which can range from deep uncertainty (unknown to science) regarding the nature of threat; to uncertainty surrounding the magnitude of impact; uncertainty over the technical effectiveness of identified mitigation measures; to uncertainty over the capacity to motivate others to adopt them, and more (see Table 1).

Table 1: Domains of uncertainty in risk assessment

- Unknown to science- novel but potentially knowable.
- Unknowable to science- phenomena or variable that cannot be measured.
- Sources of uncertainty.
- Nature of uncertainties.
- Magnitude of uncertainties.
- Statistical uncertainty.
- Scenario uncertainty- magnitude and probability of impacts.
- Effectiveness of mitigation measures.
- Interactions between variables.
- Reliability of data / evidence / indicators of infestation.
- Lack of unity amongst scientists over nature of pest / disease, causation or impacts.
- Profile of stakeholder and public concern.
- Economic impacts.
- Institutional impacts- e.g. reputational damage.
- Legal implications.

In situations of deep uncertainty and / or situations where published findings require a high degree of distillation and interpretation, the role of scientists and technical specialists places a strong reliance on expert judgement. Critically, expert judgement in such contexts embodies, not only providing informed opinion over key variables and how they operate but, providing an appreciation of aspects over which there is uncertainty and any arising implications. For the scientist, a core challenge is to portray uncertainties in ways that are accessible to target audiences but which, at the same time, do not convey the impression that science in the area is fundamentally speculative offering no clear way forward.

In the context of evidence based public policy, it is widely recognised that there is an inherent

tension between the desire for clarity, certainty and lack of ambiguity within policy strategy and delivery functions and the ambiguity, uncertainty and associated debate that routinely characterises the practical applications of scientific insight (see, for example, Solesbury 2001).

"However, effective communication of uncertainties to policy makers and other stakeholders is important, uncertainties have implications, influence policy strategy, what is claimed and [has] real world impacts" (Wardekker et al, 2008).

Policy delivery uncertainties

Evidence based public policy is more than the identification of sources of harm, determining measures for its control and caveating conclusions through acknowledging uncertainties in the underpinning (biological) science.

From the perspective of propagating the adoption of mitigation measures to address the threats posed by pests and diseases, significant uncertainties surrounds the capacity of g/Government and its Agencies to achieve this. Issues of behaviour change are central to this process, particularly where there is a desire to motivate others e.g. landowners, growers, importers, suppliers and the general public to behave differently; most acutely in the absence of dedicated legislation. A number of sources of uncertainty surrounding policy delivery are summarised in Table 2 below.

An appreciation of uncertainties of this nature is potentially of high relevance to policy makers, in addition to their appreciation of uncertainty over natural science components. There have been extensive evidence reviews in other public policy domains that address issues relating to (i)- (vi) in Table 2. Their findings will not be discussed here as, while complementary, they lie outside the scope of this review.

The purpose of highlighting uncertainties surrounding policy delivery is that such considerations are of relevance to assumptions made in the risk assessment regarding mitigation measures and their impact. This distinction also serves to highlight the fact that the boundaries of uncertainty over risk control extend beyond the process of risk assessment.

Table 2 Examples of sources of uncertainty in policy delivery

<ol style="list-style-type: none">i. Reactions / orientations of stakeholders to the pest or disease.ii. Reactions / orientations of stakeholders to the proposed measures.iii. The extent of variability in stakeholder perspectives (referenced to i and ii).iv. The most appropriate methods for engaging with stakeholders.v. The most effective models / techniques for influencing stakeholder attitudes and behaviour e.g. motivating adoption of engineering controls / good practice.vi. The capacity of government bodies and surrogates to realise the necessary metrics of impact on target populations to render mitigation measure effectiveness.vii. And more...

4. Communicating uncertainty

“Historically, the most common approach to uncertainty in policy analysis has been to ignore it” (Morgan and Herrion, p.43)

We will first establish a framework for considering the communication of risk and uncertainty within which to explicitly consider the communication of uncertainty within the PHRR.

Communication is a process of *exchange* of information. A seminal National Research Council publication (1989) notes that this consists of the transfer of risk information often from experts to non-experts and back again. These risk messages consist of *‘(1) facts or hypotheses about the level of risk that exists within a system; (2) the significance or meaning of the risk relative to other issues of concern; or (3) decisions, actions or policies that may be undertaken to control it’*. It is important to note here that, when we refer to the risk information that is exchanged – we are talking much more broadly than elements relating to the hazard / vector. As NRC make clear, relevant exchanges also, *“express concerns, opinions or reactions to risk messages or to legal or institutional arrangements for risk management”* (p.21).

In fact, to characterise communication as a two way exchange is at risk of over simplification. Information about uncertainty takes place in multiple, simultaneous and asynchronous

exchanges between non-experts and between experts as well as between experts and non-experts. So for example, in the context of the risk register, on the one hand we are considering the way in which (e.g.) policy officials make sense of the way in which uncertainty around plant health and disease is communicated to them by scientists but of course policy officials in turn are often required in turn to communicate risk and uncertainty both to ministers and possibly to concerned stakeholders and publics – and in anticipation of doing so are often highly sensitised to their potential responses.

Headline findings

- *There are three dimensions of communication - micro, process and macro.*
- *The focus of concern / need for information on uncertainty may vary between stakeholders.*
- *The focus of concern / need for information on uncertainty may vary as threats from pests or diseases and institutional reactions to them mature.*
- *There may be benefits from a layered approach to communicating uncertainties*
- *Identification of a single policy option may be inconsistent with acknowledgement of uncertainty and obscure a clear view of areas of agreement and disagreement and the reasons that lie behind these.*
- *One of the challenges for communication of uncertainty in relation to a risk register is that the process for identifying uncertainties should be proportionate to the process for characterising the risk and congruent with the purpose of the risk register.*
- *Although it may not be acknowledged, the characterisation of risk and uncertainty is linked to values and preferences*

A communication framework

"Effective risk communication is important. Without it the most carefully performed risk analysis may be useless... Effective risk communication involves a variety of questions, some fairly narrow and technical others ...broad." (Ibeckk and Morgan, 1987).

Before proceeding, it is worth considering in more detail what is meant by communication in the context of risk and uncertainty; in particular with respect to defining parameters and boundaries.

Mere mention of the words stakeholder and communication in a room full of policy makers and technical specialists is prone to elicit a range of foci. Various: complexity of language, font size, presentation medium, interactive display, trust in source and similar will all likely be cited. All, and more, are relevant. Because the word communication means different things to different people, and can bring different elements to mind when mentioned, it is perhaps useful to think of communication elements as requiring consideration at three levels (refer to Figure 1):

- At the most basic (micro) level communication is about simplifying complex information to increase comprehension, extending issues of format etc. An, essentially, technical process on which there is extensive textbook guidance and other published insight (see section 8).
- Beyond this lie elements relating to characterising the target audience(s) and ensuring that messages are of good fit with their informational needs, combined with mapping the most effective transmission mode(s) / pathway(s). This can, and necessarily should, involve more than standard stakeholder mapping; and may benefit from commissioning a modest amount of empirical research with stakeholders. The mental models approach summarised in section 7 represents a useful technique in this respect.
- At a macro level lie elements relating to stakeholder perceptions of the relationship between the source (communicator) and the issue under consideration, i.e. the impact of even the best technically crafted and delivered message will be of limited impact if the source is not viewed as credible or trustworthy.

All three components are not relevant to all communications. However, judgement over scope needs to take place at an early stage.

- A focus on micro elements alone may prove sufficient when dealing with a simple, non-controversial issue, where the information preferences and needs of the target

audience(s) are already well mapped.

- Where there are gaps in communicator knowledge regarding: the information needs of the target audience(s) (e.g. extant mental models of the issue), effective communication channel(s) and projected metrics of impact, process elements need to be considered.
- When dealing with complex issues, and / or multiple target audiences with different needs / understandings (mental models), using different communication channels, particularly for emotive high profile issues, all three components may need to be considered.

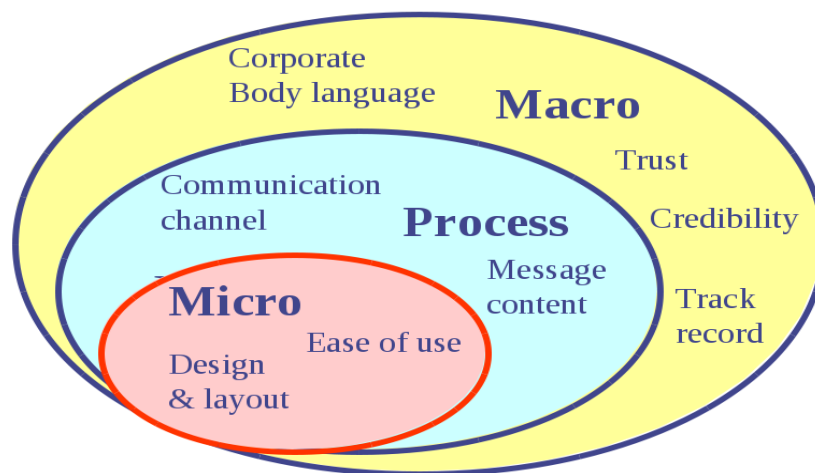


Figure 1: Concentric Model of Communication

The mandate to communicate uncertainty

It is useful to briefly consider the mandate to communicate and to be transparent about uncertainty. Being transparent about uncertainty contributes to several of the desirable principles involved in assessing risk (Grey et al., 1998). The increasing requirement for transparency in risk management (House of Lords, 2000) is arguably rooted in the examination and interrogation of the science and policy interface following the BSE crisis. The government responses to the BSE Inquiry itself was explicit about this, noting, '*the need to be open about uncertainty and to make the level of uncertainty clear when communicating with the public*' (HM Government, 2001).

The work of Stirling (2010) is explicit regarding the value of characterising and communicating scientific uncertainty. However, the focus of his thesis is not on the process of communication per se, rather it is on the process of producing what will then form the contents of that communication. His influential framework is explicit about the importance of acknowledging incomplete knowledge and of avoiding “the temptation to treat every problem as a risk nail, to be reduced by a probabilistic hammer” (p.1030). When knowledge of probabilities is problematic (as it is under uncertainty) Stirling argues that the plural and conditional nature of knowledge should be met with plural and conditional methods of science-based advice. A single interpretation masks the uncertainty and also renders invisible the assumptions that have been made in order to arrive at that interpretation, as well as other equally plausible interpretations. In essence, the case that Stirling makes is that the development and communication of policy options should reflect the completeness of our knowledge. It is also argued that, although of course not ruling out conflict between stakeholders, presenting uncertainty in a way that discourages single conclusive policy interpretations, reconfigures the inter group dynamics away from a ‘winner takes it all’ scenario. More recently, a more traditional risk analysis scholar has concurred with this view. Morgan disagreed with the view expressed by Bolger and Rowe (2015) that, “for policy making a single representation of the uncertain quantity and related probability is needed” – noting that, it may be *desired*, but that such a representation will be likely to obscure what might be important disagreements, the reasoning behind which it is important for policy makers to know about.

Fischhoff (2015) is another risk scholar that is explicit about the value of communicating uncertainty: ‘...*conveying uncertainty is essential to science communication*’ (p.13664). He argues that working out what do first means deciding what the decision to be made is about. Is it a decision about whether it is time to act? About which of several fixed options is the best? Or is it about which potential options are possible? For all of these types of decision though uncertainty needs to be dealt with in the same way:

- “(i) Characterizing uncertainty, by identifying the issues most relevant to the choice;*
- (ii) assessing uncertainty, by summarising that information in a useful form; and (iii)*

conveying uncertainty by creating messages that afford decision makers the detail that their choices warrant” (p.13664)

The decisions in the Plant Health Risk Register are essentially about deciding whether and when to act. He suggests a process for characterising and assessing uncertainty that enables a communication along the following lines:

‘Considering the variability of the evidence and my assessments of the internal validity of the studies that collected it, their relevance to the decision making domain and the strength of the underlying science, I am 95% certain that the true value of the critical outcome is between Y and Z

What are the challenges of communicating uncertainty within the risk register?

No matter what method or combination of methods is used to characterise uncertainty within the risk register, as we move on to consider the challenges in communicating uncertainty, it is important to note the possible benefits - in theory at least - of incorporating uncertainty assessment within the risk register. These might at least include the potential for highlighting uncertainties that are relevant to decisions around prioritisation of mitigation actions, or help identify uncertainties where there would be value from further investigation.

This draws on the work of Levin (2006) who argues that to enable well founded regulatory decision making, decision makers should be informed about all ‘decision relevant uncertainty’ which means specifying, *‘(1) the character and degree of uncertainty about the assessment variables, (2) the possibility of reducing the uncertainty, and (3) the degree of agreement among experts. Furthermore, it is required that (4) the information covered by the previous conditions is presented in a clear and comprehensible way.’*

However risk registers have some particular characteristics that arguably constrain the options that there are for depicting uncertainty. Note, for example, the observation of Breakwell (2014) about risk registers:

“the message here to managers must be to keep the treatment of these ratings simple. They are not engaged in a statistical exercise. Risk mapping should be used as a tool for raising awareness and improving foresight” (p.224)

The take home point here is that risk registers are a simple tool. The process by which risks are characterised is relatively simple – certainly much more than is the case for a pest risk analysis. Additionally the process of deriving uncertainty should be cost effective and fit for purpose. The process for identifying and characterising uncertainty should be proportionate to the process for characterising the risk and congruent with the prioritisation purpose of the PHRR – and, of course, with the number of pest diseases in the PHRR.

The ‘congruence principle’ (Wallsten & Budescu, 1995) suggests that this sense of proportionality is rather important: people are more likely to value and accept expressions of uncertainty, the precision of which are in line with their expectations of the uncertainty in the domain. Thus, a format for expressing uncertainty that matches the expectations for the domain should be chosen. However, we can extend this point and suggest that it is important that any expressions of uncertainty that are to become embedded in the PHRR are not seen as incongruent either with the simplicity of a risk register, with the process of deriving uncertainty estimates, or its prioritisation purposes.

5. Reasons for (expert) reservations about communicating uncertainty

The changing profile of public and stakeholder concern about tree disease has recently been articulated within a consideration of the Social Amplification of Risk Framework (SARF) (Pidgeon & Barnett, 2013). Here, SARF was used to situate an exploration of the transition – in a relatively short space of time - from a scenario where the need to *increase* public concern was noted, to one where there was political concern about *heightened* levels of public concern. The authors argued that this changing pattern of concern was explicable in the context of a range of factors shaping public perceptions:

*“an apparently **novel** pathogen posing an **inevitability of disease spread** and **irreversibility** once a site has been infected, a threat to a **highly valued** part of the British landscape and symbol of identity, and **uncertainty** about the outbreak causes and underlying science”.*

It is against this backdrop that we can consider possible grounds for expert reluctance and reservation around communicating uncertainty.

In the wake of the post BSE Phillips Report, experts are well aware of the expectation that uncertainty should be communicated. As noted earlier, Frewer and Salter (2007) argued that increased transparency lays bare uncertainties and variability in risk assessment but insofar they are not articulated within the risk communication process, this has the potential to increase distrust and concern. Paradoxically, one reason for expert reluctance to communicate uncertainty is that it is the articulation of uncertainty that will cause distrust and disquiet of publics and stakeholders to increase with the possibility of this translating into even more tangible political pressures. Wynne (1992) characterises those concerns as follows:

“In addition, public distrust in science and scientific institutions would increase and panic and confusion regarding the impact of a given hazard on human health and the environment result”

Certainly there is evidence that expert reluctance to be explicit about uncertainty, in part, stems from the belief that the public require assurance or that this will undermine expertise. When expert views about the public reception of uncertainty were explored, the dominant characterisation of the public was one where they were vast as unable to understand the process of science. Experts also made a link between increased exposure to information about risk uncertainty and a decline in public confidence in science. It was concluded that the remedy to this was simply to be to produce more, better and clearer information aimed at lay stakeholder – a further manifestation of the intuitive, but widely discredited, knowledge-deficit assumption.

Headline findings

- *Policy officials are sensitised to the scenario that the communication of uncertainty around tree disease may cause concern and conflict that they believe are unwarranted.*
- *Distrust and reputational damage may result from obscuring uncertainty*
- *Given that many risks are not experienced directly, the media are key in re-presenting these*
- *The media report much more than technical estimates of risk and uncertainty. The way in which events are framed may highlight uncertainties that are not part of technical estimates – for example uncertainties about how the risk is being managed.*
- *A simple view that the media always sensationalise and exaggerate is not backed up by evidence although scientific uncertainty may be depicted as a cause for concern through a focus on social aspects of uncertainty.*
- *The characteristics of risk that attract media attention are well established and the depiction of uncertainty around (e.g.) who is to blame, conflict, cover up, what the implications are likely to further consolidate this attention*
- *An appreciation of journalistic practices will increase policy understandings of what is newsworthy and why and of the ways in which the story is likely to be covered*

Given that the perception of uncertainty is, indeed, one of the conditions that can be linked to an escalation of public concern, this may sponsor concern amongst scientists and policy makers that the communication of acknowledged uncertainty may act as a pivot point, triggering unwanted intensification of the perceived risk (Breakwell & Barnett, 2001). There may be particular apprehension, or indeed the incomprehension on the part of experts where these initial concerns are linked to further ‘ripple effects’ such as:

“market impacts (perhaps through consumer avoidance of a product, country or area), calls for regulatory constraints, litigation, community opposition, loss of credibility and trust, stigmatisation of a facility or community, and investor flight” . (p.8)

One of the escalations that experts may fear is that being explicit about uncertainty may bring an increased likelihood of conflict with stakeholders. Arguably, however, conflict and reputational damage is as least as likely to result from *obscuring* uncertainty. Secondly, it should not be assumed that increased public or stakeholder concern – or the conflict that can be linked to this - is always undesirable. Lay action and concern can be desirable where, for example, experts are seeking to increase appreciations of risk and encourage preventative actions. Thirdly, a historical perspective makes it clear that the actions of interest groups and stakeholders may be generative of important social change. Pidgeon and Barnett provide examples of this in relation to workplace safety regulations and right to know legislation around sex offenders.

The role of the media

Both scientific experts and policy officials may have particular concerns around media reporting of risk and uncertainty, in particular that the media plays a key role in affecting public perceptions of risk - by intensifying concern in a way that is disproportionate and unwarranted in the eyes of experts. We will, thus, consider the evidence for media portrayal of risk as well as considering how best to communicate risk and uncertainty to the media.

SARF makes it clear that our experiences of risk and the ways in which we makes sense of it are a product of how societies, institutions, organisations and individuals (in SARF terms, ‘stations of amplification’) process assessments of the risk as well as a product of any direct experiences that we may have. Given that many risks are not experienced directly, the indirect experiences that we have through being exposed to and making sense of information about them - are crucial. Unsurprisingly then, within SARF the media are considered as a key station of social amplification.

“Particularly important in shaping group and individual views of risk are the extent of media coverage; the volume of information provided; the ways in which the risk is framed; interpretations of messages concerning the risk; and the symbols, metaphors, and discourse enlisted in depicting and characterizing the risk” Kasperson & Kasperson (1996).

When using SARF as a framework within which to consider public concern around Chalara and tree disease more generally, Pidgeon and Barnett (2013) note that media coverage could not be dismissed as uninformed or sensationalist, although the tone of many headlines were redolent of an impending crisis linked to questions as to who was responsible for this state of affairs.

There are two main themes to be considered here: (a) How the media report risk and uncertainty and why, and (b) the relationship between media coverage and non-expert/lay views of risk and uncertainty

How do the media report risk?

It should be made clear at the outset that, although we are talking about ‘the media’ - as is the norm within SARF – in fact there are many versions of the media – local, national, newspapers – tabloid and broadsheet – TV, radio and of course increasingly there are myriad ways in which people interact with media online, a proliferation of user generated content; increasing numbers of both sources and channels. This online media has, thus far, received extremely limited consideration in the risk literature and no doubt this, and the way it is used alongside offline sources – is likely to be a focus of future research activity.

Technical and expert estimates of risk, at best, are only one part of what the media report. Where they are reported it is likely to be done in the context of conflicting political goals (Nelkin, 1991) and a range of competing stakeholder economic, political and social values. Coverage of events is woven into an established set of narratives around science, the management of risk and of accountability.

In terms of how media practices affect the way in which risk is dealt with, the concept of ‘framing’ is important. This refers to the ways in which, ‘news coverage draws boundaries around an event or issue, classifying it as an instance of “X” rather than “Y” (Murdock et al., 2003)’. The framing of an event is achieved through links to similar past events, where images and metaphors play a key role in constructing that similarity. This similarity may bear

little relation to expert interpretations of the event. For example, early reporting of genetically modified foods and whether or not they may be linked to unanticipated health impacts often anchored such questions to the BSE crisis (Marris, 2001). Where there is significant uncertainty, this also means that the framing of the issue is open to contestation between interested parties. As we will see in the next section, the uncertainties that non experts are interested in tend not to mirror the narrower technical definitions of uncertainty considered by experts, but concern broader uncertainties around (e.g.) the cause, or what the best ways of managing the risk are.

Media coverage is not simply text based and may crystallise around symbols, or visual images that exert a strong positioning power on public attention (Joffe, 2008), triggering a range of powerful connotations that capture public sentiment. The form this takes may vary, ranging from humour through to images of a holocaust. Sometimes, metaphors intentionally used as part of risk communication strategies can assume a level of significance that is unwanted, extending far beyond the intentions of the communicator. For example, the metaphor of fighting a war was used as part of the call to action in relation to foot and mouth disease in the UK; later this became associated with images resonant of a war zone. In relation to tree disease, Pidgeon and Barnett (2013) suggest that “given the strong symbolic meanings of woods and trees that are linked to iconic landscapes it would be advisable for Defra to be attentive to any defining images that emerge around Chalara or tree disease more generally as they may come to embody defining views of what is at risk and who is responsible for this”.

When considering the role of the media in social amplification of risk, the general picture is unsurprisingly that – ‘it’s complicated’. However Freudenburg (1996) suggests that the view of scientific experts on the matter is rather simple – there is widespread agreement that ‘the media often distort or exaggerate’ and that a myriad of media created ‘scares’ shape public perceptions of risk. Some risk scholars have also concurred with the view that media reporting is sensationalist and exaggerated (see an overview in Wahberg and Sjoberg, 2000). Less extreme variants of this position are that a media focus on balance has the effect of undermining evidence for safety or that even though the text may be proportionate the nature of the photos and headlines undermines this (Mazhur, 1984).

The early findings of Combs and Slovic (1979) were that media coverage is largely unrelated to numbers of fatalities but to other characteristics of the situation (see Table 2 below). Even within the trajectory of a particular event there are discrepancies between the incidence and the media coverage (Miller & Reilly, 1995) i.e. increasing incidence of salmonella and decreasing media coverage of the outbreak.

However other studies have argued that media coverage has been arguably more low-key than the experts might suggest was warranted. For example, in a study of Chernobyl, it was concluded that there was a *lack* of risk information but what was reported was proportionate and even-handed (Friedman, 1987). In empirical examinations of media reporting some support has been found for the hypothesis that in fact the media 'de-emphasise the severity of hazard events' (Freudenberg, 1996). Media reporting of '*the pill scare*' (Barnett & Breakwell, 2003) suggests that journalists were aware of the impact of previous reporting on the birth control pill and women's contraceptive practices and tailored subsequent reporting to avoid any repeat of this.

The fact that, generally, the volume of media coverage does not parallel expert assessments of risk is neither surprising nor perverse, given both the agenda of the media (to provide 'infotainment') and the focus on aspects of the risk other than probability and consequence. Media reporting of risk, like public perceptions of risk, can often reflect values, identities and assessments of institutional competence. Alongside this, reporting technical uncertainties is just one part of the story. The focus may often be on other, more social, dimensions of uncertainty – *who is responsible? what is being done about the situation?* and so on. This was the case in a study of chronic wasting disease where the uncertainties that were highlighted concerned how it came about, how it was transmitted and its possible effects (Heberlein & Stedman, 2009). These authors suggest that various strategies, such as personalising the responses of scientists, were used to translate 'normal' scientific uncertainty into a cause for concern.

Other work on media effects has sought to identify the characteristics of an issue which attract the greatest media attention - see Table 3 below

Table 3: Media triggers - adapted from Department of Health (1999)

A possible risk to public health is more likely to become a major story if the following are prominent or can readily be made to become so:

- Questions of blame
- Alleged secrets and attempted cover-ups
- Human interest through identifiable heroes, villains, dupes etc. (as well as victims)
- Links with existing high-profile issues or personalities
- Conflict
- Signal value: the story as a portent of further ills ('what next?')
- Many people exposed to the risk, even if at low levels ('it could be you!')
- Strong visual impact (e.g. pictures of suffering)
- Links to sex and/or crime

The Pidgeon & Barnett (2013) report on Chalara and the social amplification of risk suggested that several of these factors were applicable:

'widespread exposure of the tree population, visual impact (images of both healthy and infected trees), the possibility of blame for allowing a known risk to enter the UK, potential conflict along ideologically significant lines (e.g. between the UK and other EU governments regarding risk control measures), and high signal value (what does this episode portend about other threats to tree health and plant biosecurity, or about the risks from the systems for managing the natural environment?). (p.7)

In line with this, early work by Frewer et al. (1993) depicts the way in which media risk reporting tends to be different for hazards (and perpetrators) with different characteristics. It was also the case that where numbers and probabilities were mentioned, conflict, uncertainty and pressure group activities were not – and vice versa. Research has demonstrated that the presentation of risk in local media are sensitive to qualities of the community in which they are located (Griffin et al. 1995).

Petts et al. (2001) note three key developments in the media landscape: the increase in number of NGO's and their increasing professionalization; the increased visibility of the concept of 'spin' and associated growth of the public relations industry, and; the rapid rise of

the internet. In terms of the significance for the consideration of the communication of risk and uncertainty in the media, since the time of Petts' analysis this has arguably been eclipsed by the risk in user generated content in social media.

Underlying these developments however, Petts et al. (2001) there are a series of consistent criteria for news selection (see Table 4)

Table 4: Criteria of news selection around the reporting of risk and environmental issues

- *An orientation to events.* News focuses on interruptions to the normal flow of activity (an accident, a protest, a political speech, a new piece of research) not on underlying processes or continually unfolding conditions. As a consequence, the media may fail to report on risks until some dramatic event occurs, leaving accidents and illnesses that kill people every day of the year unreported
- *Novelty.* There is a preference for material that introduces new issues or moves an existing story on. This produces relatively compressed issue-attention cycles. Stories die quickly and reappear only if another newsworthy event breaks, producing a pattern of peaks and troughs.
- *Scale.* Events are more newsworthy if they involve or affect large numbers of people or have wide ranging implications for the way people conduct their everyday lives.
- *Conflict and drama.* News trades in material that involves controversy and /or dramatises the seriousness of actual or potential risks. Journalists themselves talk about the attractions of scientific controversy. As media coverage of controversy increases so does public opposition. However, as media reporting tails off so do public risk perceptions, regardless of whether the reporting is positive or negative. Research also suggests that by drawing attention to disagreements amongst experts and providing space for different accounts, media may convey the impression that there is no agreed view on a particular risk, leading the public to 'err on the side of safety'.
- *Resonance.* News taps into existing public anxieties and frames stories in terms of already familiar events and scenarios. The coverage of GM foods, for example, consistently drew on pre-existing templates and public concern over BSE.
- *Personalisation.* News seeks to invest public issues with human faces by focussing on key actors or presenting ideal typical consumers or victims.
- *Domestication.* News often looks into the immediate consequences for everyday life in households and families. A study of the BBC looking at news bulletins and what provides an item's appeal and what prevents it being effective, found that stories on genetics, medicine, and the environment that established their relevance to individual lives roused particular interest - 'pure science' did not.
- *Visualisation.* News organisations are continually searching for images that crystallise their interpretation of an event or issue. The Daily Mirror's front page, published at the peak of the initial controversy over GM foods early in 1999, showing the Prime Minister as Frankenstein's monster is a particularly vivid example.

Journalistic practices

In considering how the media communicate uncertainty, it is important to consider the way in which this is shaped by journalistic practices and norms (Bakir, 2010). The way in which information is provided to the media about uncertainty should take account of these processes. It is also useful in understanding how journalists are likely to depict uncertainty and explain why what is reported may bear little relationship to the hazard landscape as seen by risk assessors (Hughes et al. 2006). De Loe (1999) considers the characteristics of the newspapers to include difficulty in maintaining a focus on both positive and negative aspects of an issue, simplification of complex issues to increase accessibility, a focus on newsworthiness for a season until attention shifts to new issues. Long term continuous complex or multi-causal risks tend to be ignored - rather the preference is for a focus on events.

Breakwell (2014) summarises the results of an interview study with journalists about the way in which they report risk issues. The main findings from this are summarised in Table 5

Table 5: Journalist perceptions as to how they report stories about hazards and risks

- ‘Scare stories’ are a particular category of reporting that involve the possibility of harm to many/vulnerable people where that harm is largely invisible/long term/possibly fatal. They are good for audience figures. They may be a by-product of media re-presentation facts and figures. Commercial pressures make it likely that scare stories will always be part of the media landscape
- What experts may refer to as sensationalism is considered to be *infotainment* – providing information in an entertaining manner. Thus stories with no/minimal risk are less likely to be covered
- Generally journalists said that they tended to *avoid real science* in their risk stories – and they did not see their lack of expertise in this area as a problem
- Individual journalists and editors have preferences for particular types of stories and a history of examples to call upon to frame new stories
- Journalists valued proactive information delivery (see also Table 5)
- When asked about reporting events where there is little certainty, journalists said that uncertainty per se was not considered newsworthy nor was it seen as particularly difficult to handle. There was some cynicism about motives for reporting uncertainty but there was complete agreement that uncertainty should be communicated to them early on

It is useful to consider insights of the evaluation of how well uncertainty was communicated to the media in the very challenging context of the 2009 influenza pandemic. (See Table 6 below)

Table 6: Insights about communicating with the media about uncertainty from the Independent review of the UK response to the 2009 influenza pandemic

- Maintaining public, professional and media confidence in the government's response was crucial to actually delivering the response itself
- CMO (England) took great care in his media briefings to explain that numbers represented reasonable worst-case estimates against which to plan, and not predictions, and a number of journalists did report the figures responsibly. However, this was not always the case, and the impression emerged that the government was 'predicting' 65,000 deaths. This figure was then revised down significantly in the subsequent revisions.
- The concept of reasonable worst case estimates was difficult to communicate
- The Science Media Centre could be a useful partner in developing public understanding of pandemics in normal times – i.e. not during a pandemic
- Discussions with journalists demonstrated that they believed that the public were comfortable with the idea of there being uncertainty over the development of the pandemic. However use of the planning assumption figures (in the absence of any others) led to the Chief Medical Officer in England citing the 'reasonable worst case' planning assumption being 'widely reported in headlines in somewhat alarmist terms'. This also contrasted with what could be observed on the ground in terms of severity and could have risked damaging government credibility
- The Science Media Centre played an important role in helping to facilitate engagement between the media and independent expert scientists. More generally, the role that such organisations can play in creating a more informed debate that can help the government better communicate the level of risk and uncertainty was noted.
- Stronger horizon-scanning of media reporting to identify emerging themes and issues of concern may have helped DH to more proactively challenge misunderstandings and public concerns.
- Journalists across the UK praised the regular media briefings that took place – saying the levels of information given were unprecedented in a public health emergency. For their part, ministers and officials considered most media coverage to have been responsible and balanced.
- There is a clear lesson that treating the media as being responsible, and taking the time to explain and contextualise information, encouraged responsible reporting.
- Much depended on journalists being able to physically attend the briefings, as information was not proactively sent to those not able to do so. In the future new ways of proactively engaging with journalists should be considered e.g. podcasts and transcriptions of media briefings

Petts *et al* (2001) draw together a range of evidence to persuasively make the case that

“The media are not transmitters of official information on risk but active interpreters and mediators, middle-men on the field of play, who seek to resonate with social preferences and concerns and in so doing stake and maintain their position. They are entrepreneurs of meaning converting the raw material of official information and events into products which bear their particular market ‘badges’ and presentational styles”. (p.94)

What are lay responses to reporting of risk and uncertainty?

Moving on to consider the topic that perhaps receives the most attention, by volume, – does the media influence public responses to risk and uncertainty or simply reflect such?

“That the public appear concerned about a risk that risk managers and decision-makers are not concerned about is often viewed as the fault of the media”. (Petts et al. 2001)

Early work suggested that this was indeed the case, although considerable media research refutes this interpretation. It has been suggested that the volume of coverage (saturation) is important in affecting public opinion in a negative direction – independently of whether the content of risk reporting is negative or not (Mazhur & Lee, 1993). This is explainable in terms of innate cognitive bias, specifically a manifestation of availability bias (see Section 7 below), i.e. more frequent coverage renders risk information more easily brought to mind. On a methodological point however, it is important to note that much of the research linking risk perception and media coverage is correlational, i.e. it may also be the case that media coverage picks up on and is in tune with (likely) public sensibilities around an issue. This, indeed, is one conclusion of the study of the media and social amplification of risk by Petts et al. who conclude that, *“the media can only amplify or attenuate risk if they capture or resonate with an existing public mood, and even then the media are not alone in this function”*. The media may play an important role in setting agendas for public concern - that is, that the media don't tell us what to think rather they tell us what to think about (McCombs and Shaw, 1972)

Alongside this there has been considerable work over recent years that undermines the model of people being susceptible to a dominant media. This perspective points to how active

people are in their interpretation and use of the media. This does not mean that the media is not influential, or that a different interpretation from that offered by the media will necessarily result, but it does mean that influence of the media is mediated by people's everyday experiences, social interactions and the cultural resources that they possess (Kitzinger, 1999)

The research by Petts *et al.* shows that people actively interrogate risk information, they are not passive recipients and they frequently draw on multiple sources in order to make sense of risk information, seeking to take control - interpreting information in ways that allow them to do this where possible and (ideally) defaulting to filtering what they are presented with through frequently rather vague and impressionistic evaluations trust in the source, where it is not possible.

Implications for communicating risk and uncertainty

In the first instance here, it is instructive to view the BBC editorial guidelines to guide journalistic practice for reporting risk and to consider what implications these may have for the communication of uncertainty⁷.

BBC Editorial Guidelines for Reporting Risk

Using the following checklist can help ensure the context is clear and avoid distortion of the risk.

- What exactly is the risk, how big is it, and who does it affect?
- Can the audience judge the significance of any statistics or other research? Is the reporting clear about how any risk has been measured - for example the size of any research sample, margin of error, the source of any figures and the sponsor of the research?
- If you are reporting a change in the level of risk, have you clearly stated the baseline figure? (A 100% increase or doubling of a problem that affects one person in two million will still only affect one in a million.)
- Is it more appropriate and measured to ask "How safe is this?", rather than "Is this 100% safe?"
- If a contributor's view runs contrary to majority expert opinion, is that clear in our report, questions and casting of any discussion?

⁷ BBC (2010) Reporting Risk Guidelines, <http://www.bbc.co.uk/guidelines/editorialguidelines/advice/reportingrisk/reportingriskch.shtml> (accessed 21 Feb 2013)

- We should consider the impact on public perceptions of risk if we feature emotional pictures and personal testimony.
- Is there an everyday comparison that may make the size of the reported risk easier to understand? (For example, "it's as risky as crossing the road once a day")
- Would information about comparative risks help the audience to put the risk in context and make properly informed choices? Consider for example, causing undue worry about safety of the railways could lead audiences to migrate to the roads unaware that the safety risk is many times greater.
- Can the audience be given sources of further information?

From the material we have considered, it is possible to consider some of the implications of this for communicating risk and uncertainty. These particularly draw on the work of Breakwell (2014) and Petts et al. (2001).

- Media coverage of risk and any attendant uncertainties is not simply about that particular event – rather its coverage is set within and intertwined with an established set of narratives around science, management of risk and accountability and alongside other - possibly unrelated events – also being covered at that time. This perspective should constrain any expert ambitions as to how they might be able to shape the coverage of any particular event - still less affect the impact that this has.
- As elsewhere – for organisations designing communications to communicate uncertainty, it is vital to consider what it is that stakeholders and public(s) want to know rather than keeping the focus on what it is that experts think they should be told. Work is needed to discover what it is that people want to know and how this is different for different groups of people. The importance of understanding lay mental models of risk are thus important. This should be done on an ongoing – not one off – basis.
- This is also important in making decisions about the language that will be used. For example within the Hine report on the evaluation of the swine flu pandemic it was noted that some of the terms used in the communication were not clear: ‘pandemic’ was taken to mean a very severe disease, rather than referring to the geographical nature of its spread. ‘Planning assumptions’ was often taken to mean ‘likely events’.

Early empirical work would help identify these issues which can lead to reputational damage.

- Provide relatively concise accurate lay descriptions alongside more detailed information – bearing in mind that media sources may (a) produce the more concise summary themselves if you don't and (b) tend to be reticent about including detailed scientific information.
- Where it is desirable to maintain coverage of a story - new information, commentary or interpretation will need to be fed to the media.
- Managing the representation of a controversy is likely to mean active involvement rather than silence.
- A spokesperson for scientists or policy officials should ideally be someone who can tell a story in way that commands attention and appeals to a wide audience. Media sources should also have access to someone that can explain scientific information in a way they can relate to
- Identify the frames that are being used to report particular stories by particular journalists. This is necessary in order to refine a relevant refutation and to anticipate the most likely direction of subsequent coverage.
- Be proactive in providing information to the media – this is valued - and avoids an information vacuum – which will be filled.
- Take advantage of resources like the Science Media Centre
- Provide the media with regular information about uncertainty on key risk issues and link the uncertainties with a description of what is being done (both in response to the risk and to resolve the uncertainty)

- Be proactive in use of the images and symbols which are important to, and resonate with, lay publics and use visual resources to express key points.

6. What is the evidence about lay responses to uncertainty?

There are a number of challenges that arise when communicating uncertainty to non-expert audiences. Certainly, policy officials will prefer to receive unambiguous messages that provide clear evidence for particular courses of action. However, what do we know, more generally, about non expert perceptions and preferences for receiving information about uncertainty? Following the BSE crisis, there is evidence to suggest that people believe that uncertainty is unavoidable – and that denying or withholding uncertainty information is both unlikely to be an accurate representation and also signals a lack of honesty. Additionally any denial of uncertainty arguably contributes to increased distrust in risk managers and institutions responsible for science policy (Eldridge et al. 1998; O’Brien, 2000)). Work by Wynne (1989) illustrates how British sheep farmers distrusted experts because the information that they provided ignored uncertainties. In fact, the farming community knew from their own experience that there were uncertainties; it was the fact that these were not articulated by experts occasioned their distrust. Similarly, others draw attention to the ways in which it is claims of *safety* that are mistrusted (Grove White et al., 1997) and that denial of uncertainty fuels public distrust in risk regulators (O’Brien, 2000).

Headline findings

- Denial of uncertainty is likely to signal a lack of honesty and accuracy and generate distrust. People do not expect certainty although they may dislike uncertainty.
- Uncertainty may increase perceptions of risk more for some hazards – e.g. those under societal rather than personal control.
- The communication of technical uncertainty may lead to attributions about the communicator and their risk management capabilities
- Lay publics are concerned with a much broader range of uncertainties than experts are concerned about communicating

- The most unacceptable uncertainties are those associated with government inaction rather than scientific processes
- People may infer uncertainty from conflicting perspectives
- A layering or stepped approach may help communicate uncertainty effectively.

The early work looking at the reception of uncertainty information can be found in the literature around decision making under uncertainty – that is, not specifically relating to risk but to decisions relating to, the possibility of both positive and negative outcomes. Research investigating ambiguity about probabilities documents both preferences for, and aversions to, ambiguity. Generally however, greater ambiguity is associated with risk aversion (Viscusi, et al, 1991). Much of the work specifically concerned with the communication of uncertainty focuses on phenomena such as the ways in which verbal and numerical expressions of probability map on to each other (see Section 7 below) and has tended to consider the communication of uncertainty independently of the context in which such communication occurs (Fox & Irwin, 1998). Other research exploring how uncertainty relates to risk appreciation incorporates a greater consideration of context. The work of Slovic has clearly indicated the qualitative dimensions of a risk that people are most likely to attend to (dread, familiarity and so on) and uncertainty is likely to be considered differently depending on the nature of the hazard. For example, it seems that information about uncertainty increases perceptions of risk to a greater extent for hazards under societal rather than personal control (Miles & Frewer, 2003).

Uncertainty and perceptions of risk and trustworthiness

There is some evidence that uncertainty may cause people to perceive greater risk (Slovic, 1987) although the evidence is equivocal. Others (Bord & O'Connor, 1992) suggested no such relationship. Johnson and Slovic (1995) found that presentations of uncertainty did not have clear effects on the way in which environmental problems were viewed and certainly less of an effect than did attitudes toward risk and to government. In later work, the same authors (Johnson and Slovic, 1988) explored people's 'desire for certainty' with such items as, *'I would prefer a single concrete number rather than a range of numbers for the*

environmental health risks I face' and *' I would prefer that government tell me that they're just not sure about the size of an environmental health risk, if that's the case rather than giving me a range of risk numbers'* Overall, contrary to the authors hypothesis, a desire for certainty was not dominant – about 35% of respondents were above the midpoint where higher scores indicated more desire for certainty.

Johnston and Slovic (1995, 1998) note that for some communication of uncertainty will increase information source credibility, the public's trust of regulatory institutions and their ability to make informed decisions which in turn is likely to affect the behavioural response to the risk information. This was not always the case though – others questioned the presentation of uncertainty, suggesting that it brought the competence of the communicator into question and could lead to confusion and anger. It has been suggested that uncertainty negatively affects intention to get the problem solved, can be used to discount the seriousness of the threat, to excuse complacency, can easily be misinterpreted and lead to confusion (Kuhn, 1997). There is a suggestion that communicating uncertainty information can be used as a justification for inaction (Johnson and Slovic, 1998)

Interpretations of uncertainty are related both to the prior beliefs of the recipient of uncertainty information and the type of uncertainty. In relation to the first of these dimensions, Kuhn (1997) notes that the reception of uncertainty different depending on initial levels of environmental concern. For those whose initial concern was high, receiving information about uncertainty occasioned a decrease in concern. The opposite was found where initial environmental concern levels were low. Here, the communication of uncertainty was linked with an increase in concern. Similar individual differences were noted by Rabinovich and Morton (2012). Messages that communicated high uncertainty proved more persuasive and more motivating for those individuals who had a model of science-as-debate. In contrast, where science was seen as a search for absolute truth, uncertainty was less persuasive. Clearly, uncertainty does not always undermine how motivational a message can be nor how meaningful it is. One of the implications of this research is that, in order to encourage acceptance of uncertainty, there is value in encouraging engagement exemplifying that debate is key to science.

Types of uncertainty from a lay perspective

The possibility that communication of uncertainty is received differently depending on the type of uncertainty has also been explored. Here the focus is not on the types of uncertainty noted in Section 3, that are the result of expert categorisations, rather the focus is on uncertainties that might be encountered in people's lives. One such categorisation identified uncertainty about who is affected, temporal uncertainty (uncertainty about past and future states), measurement uncertainty, uncertainty due to scientific disagreement, uncertainty about the risk to humans after measurements with animals, uncertainty about the extent (or 'size') of the risk, and uncertainty about how to deal with (specifically, how to reduce) the risk (Miles & Frewer, 2003). Interestingly, it was not the case that some types of uncertainty were associated with greater concern. However, it was the case that the different types of uncertainty were associated with greater ratings of risk seriousness for some hazards (such as genetically modified foods and pesticides), than for others (BSE, high fat diets and salmonella). The authors surmise that uncertainties may be more problematic for hazards low on personal control and high on societal control.

In a linked study focusing on food risk (Frewer et al., 2002) qualitative work was used to derive the possible meanings of uncertainty from the perspective of the non-expert participants (see Table 7)

Table 7: Non-expert perspectives on sources of uncertainty

1. The government lacks definite knowledge about the topic
2. It is not possible for scientists to have all the answers
3. The government's statement is based on conflicting information
4. The information provided is the best available at present, but things may change in the future
5. The government is unsure about the extent of the problem
6. Scientists disagree with each other on the subject
7. The government is unsure whether there is a problem or not
8. More scientific work needs to be done on the topic
9. The government is withholding information from the public
10. There really is a major food safety problem

The study then explored the acceptability of each of these types of uncertainty, as well as how likely it was that where there was uncertainty it was due to each of these things. The study found that participants claimed that information about uncertainty around food problems was wanted as soon as it was identified (rather than when there was less uncertainty, complete uncertainty or not at all). The ten types of uncertainty listed in table 6 were rated similarly in terms of their likelihood, but rather differently in terms of their acceptability. Least acceptable were statements related to government inaction (9, 10, 7, 5, 1, 6 – in order from least acceptable) and most acceptable were those related to scientific processes in risk assessment (8, 2, 4, 6 – in order from most acceptable). Clearly, some types of uncertainty are more acceptable than others. This chimes with the more sociological perspective provided by Freudenberg (1993) who, moving away from a focus on individual perceptions of risk, considers the significant explanatory power afforded by concerns about institutional recreancy, “the failure of institutional actors to carry out their responsibilities with the degree of vigour necessary to merit the societal trust they enjoy” (p. 909).

Breakwell and Barnett (2002) suggest that there are four prime types of uncertainty that those communicating risks might acknowledge: uncertainty with regard to (a) who will be harmed (b) what harm is involved (c) when the harm will occur, and (d) why the possibility of harm exists. Each of these can engender the further uncertainty as to how the hazard can be controlled. This study found that different types of uncertainty did have different effects upon risk estimates; specifically that uncertainty about who was at risk resulted in higher risk ratings than did uncertainty about when the harm might occur. Notably, little attention has been given within the literature to the possible effects of moving between different types (or degrees) of uncertainty across the lifetime of the hazard.

It is also worthwhile to consider the distinction Breakwell and Barnett (2002) make between acknowledged uncertainty and ‘inferred uncertainty’. This refers to the additional level of uncertainty that is introduced when alternate sources of risk communication provide conflicting risk estimates. Bearing in mind the interests of industry, of the regulator, the consumer and of a range of pressure groups, it is likely that g/Government communications (whether or not they acknowledge uncertainty) will take place in a context of dissenting voices. Indeed, interest groups may employ their own scientific experts which add both

science and uncertainty to the debate. Johnston and Slovic (1988) also explored the scenario where they consider disagreement among scientists as a form of uncertainty – they found that most scientists agreeing was not persuasive – questioning of the motives and allegiances of scientists lay behind this scepticism. It seems to be the case that, even if scientists choose not to communicate uncertainty, given the media focus on balancing information from one source from another source (see above) and given the increased opportunities for stakeholders from a range of positions to comment, as well as the increased range of channels through which these views can be shared, disagreements (and the consequent inferences of uncertainty) are likely to be highly visible.

Breakwell (2014) provides an overview of the ways in which uncertainty can become public

Proactive Explanation	The institution managing the hazard chooses spontaneously, without duress or prompting to explain the uncertainty associated with their risk estimates
Reactive Explanation	The institution responsible for the hazard explains the uncertainty after some event or action on the part of others calls for further clarification of the risk estimate
Revealed	The uncertainty can be disclosed or proclaimed by sources other than the institution managing the hazard (e.g. the media can run stories of the ‘hidden facts’ or ‘hidden ignorance’)
Emergent	The uncertainty can be inferred by the public rather than stated by any sources (this can happen when there are conflicting expert sources offering different risk estimates to the public; the mere existence of alternative representations can suggest uncertainty)

Trust is particularly important and is the default reference point for interpreting information about risk and uncertainty where there is an absence of knowledge. This has clear implications for the communication of risk and uncertainty. When events have triggered heightened public concern, according to the Trust, Confidence and Cooperation Model (Earle & Siegrist, 2006) it is vital to appreciate the difference between trust – which is based on ‘morality information’ that is it is adjudged with reference to values – and confidence, which is based on performance information. ‘Trust dominates confidence’, thus in anticipation of non-expert sensitivities around the communication of uncertainty it is vital to be aware of the values held by those to whom communications of risk and uncertainty are being targeted. One method for doing this and that easily allows values to be tracked over time is explained in Section 8. Another implication of the dominance of trust is that simply providing

information about indicators of confidence, i.e. evidence, ability, experience, competence is not effective in producing cooperation where trust is lacking.

As we have seen, we have some knowledge as to the situations in which the reception of information about uncertainty will be more or less acceptable. It is not just a question of the content of that communication. There is much we do not know about how the vehicle within which the uncertainty estimate is delivered matters (i.e. in terms of our current consideration - the risk register. Does the timing and rate of repetition of uncertainty messages matter? (Breakwell, 2014). There is much we still do not know.

Uncertainty is always about something, and communicators of uncertainty need to take account of different types of uncertainty, and make distinctions between them, and reference this to the broader context of the object of uncertainty. As Frewer (2004) notes, lay people routinely make distinctions between lack of knowledge, that presents as ignorance, and lack of knowledge due to unknowable elements, as well as uncertainty over differences of scientific opinion (the latter being complicated by the scope for inferences of partisan perspectives e.g. MMR vaccine). Similarly, official declarations of certainty / high confidence, tend to sponsor scepticism where the inherent uncertainty of the issue is transparent, e.g. BSE.

A challenge for communicators is that the assessment of complex high impact issues routinely embodies an array of uncertainties, the breadth of which is prone to increase beyond aspects relating to environmental impacts, to elements relating to institutional (in)action and the effectiveness of mitigation measures as the issue matures, i.e. the focus of stakeholder concern is prone to evolve as risks and institutional reactions to them evolve / become manifest. Moreover, the nature and relative salience of uncertainties that are relevant to different lay audiences can be predicted to vary as a product of the threat identification / mitigation⁸ maturation process.

Assuming that a pest or disease arouses concern amongst stakeholders, a predictable threat

⁸ Including instances where the policy decision is not to introduce mitigation measures.

maturation profile might be characterised as follows:

- During the initial period, following 'discovery', the focus will likely be on the nature and magnitude of potential impacts (losses).
- As the threat manifest, attention will foreseeably evolve to debates surrounding the choice and projected effectiveness of mitigation measures (including secondary impacts).
- Once mitigation measures have been applied, and evidence of their impact begins to emerge, the focus may shift to debates over their suitability and sufficiency.

Additionally, institutionally, there may be a need to refer to uncertainties post-hoc, in the context of justifying choices, (in)action taken and resources dedicated to managing the threat, e.g. where these prove insufficient / ineffective in the case of profound impacts or are deemed by others to be overly cautious where impacts turn out to have been over-estimated.

Layering - a strategy for effective communication?

In view of the multifaceted and time-sensitive nature of communicating uncertainty, a number of authors advocate a layered⁹ (stepped) approach of progressive disclosure (see Table 8). *"A great deal of research in psychology shows that when people receive too much information at one time, or information that too seriously conflicts with their pre-existing beliefs, they will be inclined to ignore, reject or simply not act on the whole package of information"* (Hinkel et al, 2011; also see Guimaraes and Quintana, 2002, Klopprogge, 2007; Wardekker et al 2008).

It is not quite clear from the accounts provided whether what is envisaged is limited to a layering of material, in the manner of a web-site, such that headline information appears on 'page one' and individuals, so motivated, have the opportunity to investigate 'deeper' (page 2 and beyond) or whether the idea of layering generalises to sequential disclosure, over time, i.e. a planned, phased approach to disclosure. However, if sequential disclosure is intended, this will need to be performed with some skill and care to avoid fostering the perception that

⁹ A concept borrowed from human computer interaction, widely encountered in web-site design.

access to knowledge over uncertainties is being rationed, given the potential for this to sponsor suspicions regarding the motives of the source.

The authors make no reference to layering of uncertainty information as a means of managing structural evolutionary elements, characterised as risk / threat maturation above. However, the concept would appear to reflect alignment with meeting a need to shift the focus of communication content sponsored by this.

Table 8: Progressive disclosure - Source Kloprogge et al, 2007

	Outer PD layers	Inner PD layers
Contents	Uncertainties integrated in the message (implicit in semantics e.g. 'may' or 'might')	Uncertainties mentioned separately and explicitly
	Uncertainties as essential contextual information referenced to assessment results	Uncertainties as part of scientific account of the approach used in research and assessment results
	Uncertainties translated to the political and social context	Account of the 'bare' uncertainties form a scientific perspective.
	Evidence of policy relevance of uncertainties	Balanced account of uncertainties in all parts of the assessment
	Emphasis on implications of uncertainties	Emphasis on the nature, extent and sources of uncertainties
	Implications of uncertainties for the assessment results and arising policy advice given	Implications of uncertainties for representativeness of a study, value of the results and further research
Style	Scientific information translated into 'common language'	Scientific information with a high level of technical sophistication
	Use of jargon to be avoided	Use of jargon allowed
Degree of detail	Details only if considered policy relevant	Highly detailed (each layer offers more detailed information than the previous PDI layer)

7. What heuristics and biases affect the characterisation and interpretation of uncertainty and related decision making?

Recognised sources of decision bias

This section provides an overview of the extensive literature on recognised sources of bias in decision making in the context of uncertainty. It draws heavily on insights from cognitive psychology, but it is informed and elaborated upon through reference to complementary insights from social psychology, sociology and social anthropology. This latter has the effect of broadening the perspective, beyond traits exhibited by all individuals (in varying degrees), to elements that reflect social and cultural dispositional and process related influences on decision making in the context of uncertainty.

A central assumption of neoclassical economics is that human decision making represents a fundamentally rational process, where individuals select options that generate maximal expected utility (essentially gain / benefit / value). However, while remaining a core assumption within mainstream economists', common experience is that under conditions of uncertainty people are prone to choosing options which deviate from rational-actor assumptions. This phenomenon is widely recognised amongst cognitive, social and cultural scientists, and represents a core focus of the contemporary influential public policy orientated texts *Nudge* (Thaler and Sunstein, 2008; and *Think* (Kahneman, 2011).

It would be misleading to interpret the substantial research base highlighting lapses from rational decision making as implying that this is a dominant characteristic of human decision making. Most decision making is essentially rational, or at least reflects internally consistent processes. What follows relates to the interplay between situations and cognitive processing that can lead to deviations from rational choice in the context of uncertainty.

The largest contribution to insights in this area, by volume, comes from cognitive science¹⁰. A central finding here is that the interaction between the manner in which options are

¹⁰ There are complementary insights from social psychology, sociology and social anthropology

presented and cognitive processing characteristics can produce a range of predictable choice biases (or at least deviations from rational choice in the terms defined by neoclassical economics).

The relevance of these findings to the current endeavour is that they offer insight into how people process information and make choices, based on their intuitions and inferential sense-making. This insight can be used to inform thinking regarding the formulation and presentation of communication material in ways take account known sources of bias.

Despite its intuitive appeal, the more fruitful perspective here is not one of *'how do we find ways to make people more rational?'*, or *'how do we educate people to improve their understanding of expressions of risk and probability?'*, rather it is *'how should we use an appreciation of known decision-making characteristics (in particularly fallibilities) to inform how we communicate over issues of 'uncertainty?'*, in order to avoid / mitigate sponsoring decisions that result in poor (sub-optimal) or inappropriate choices (Royal Society 1992; Fischhoff, 1995). This reflects the core perspective of the influential policy orientated text *'Nudge'* (Thaler & Sunstein, 2008).

There is extensive evidence that human beings are prone to exhibit an array of lapses, biases, and other deviations, from formal logic in decision making in situations of uncertainty. They are also prone to taking mental short-cuts, (applying simple heuristic rules of thumb) rather than adopting a systematic approach to the consideration of relevant variables. By extension, this can embody affective / emotional elements and / or draw upon, socially derived, shared understandings, values and norms.

"Uncertainty is never expressed in a vacuum, it is always about something" (Rowe, 2010. p.33). Uncertainty has a context when it relates real world issues and people's contemplation is not necessarily limited to their prior knowledge understandings and associated intuitions, rather, *'filtered'* through underpinning beliefs, dispositions and orientations. In this they may draw upon references broader than the technical properties of the issue under consideration, e.g. beliefs regarding the motives of key stakeholders, attitudes to regulation and relative primacy ascribed to environmental issues and economic objectives. In essence, people

construct mental models to make sense of their world, and which make sense to them. Mental models¹¹ amount to characterisations and mappings of causal linkages between variables (physical, social and environmental). Education, past experience, general intelligence and cognitive style (and more) sponsor differences between individuals in the degree of competences and sophistication of understandings of phenomena and associated interactions.

However, the world is a complex place, and one in which human beings are adapted to using cognitively economical ways to characterise salient variables to meet their needs. While there are differences in the completeness and sophistication of people's mental models, particularly in the area of specialist technical knowledge, all individuals exhibit a tendency to apply heuristic (rules of thumb, educated guesses and intuitive judgement) as an integral part of their sense-making / decision making process, particularly when dealing with complex, unfamiliar or uncertain phenomena.

It is also, perhaps, worth keeping in mind that environment science, in common with other science and engineering disciplines, adopts an analogous strategy when selecting a sub-set of variables for manipulation in models designed to predict uncertain future outcomes, e.g. rates of migration, or infestation referenced to background rises in average temperature.

Heuristics - mental short cuts and rules of thumb

Key findings:

- *People are disposed to use (heuristics) when decisions are complex, time consuming or contain unknown / unknowable elements.*
- *Heuristics relate to the process of dealing with a cognitively difficult problem (or time sensitive issue) by selecting and answering a simpler question.*
- *Heuristics can provide a useful focus and sponsor new insight but they can also lead to important omissions.*
- *Heuristics relate to 'pattern cognition' - but can sponsor classification error, e.g. failure to take account of novel features of new situations.*

¹¹ The concept of a mental model is a heuristic

- *Heuristics and cognitive biases operate in a symbiotic manner in information processing and are exhibited by all individuals (lay and expert), particularly when at the fringes of their knowledge on an issue.*

Recourse to heuristics can be both habitual and a conscious process used in the evaluation of information to inform decision making. People make extensive use of heuristics in everyday situations. They are an essential tool for dealing with a complex world. Put simply, they are short-hand inferences based on a sub-set of what individuals consider to be the most salient variables in a given situation. Arising inferential sense-making draws, in large part, on prior experience and pattern recognition, allowing to people economically (in a cognitive sense) navigate their way around their world. Experienced car drivers, for example, automatically apply a range of heuristics; less experienced drivers less so, or at least tend to have a smaller and less sophisticated repertoire in this respect (Hale and Glendon, 1987). Under most circumstances heuristics provide a sufficient, if not always optimal, solution.

A notable feature is the tendency to over-apply heuristics, e.g. failing to take account of novel differences when encountering what, at first sight, presents as a familiar situation - to which a familiar solution might be applied.

People also tend to apply heuristics as a means of saving time and effort. When faced with a car that won't start the experienced recovery patrol officer will likely first check the fuel supply, then look for a loose ignition lead, before adopting a more methodical approach; for two reasons (i) this strategy has worked well on previous occasions; (ii) if it works there will be a time (and effort) saving. They may also fruitlessly spend considerable time applying a series of such heuristics (essentially hypotheses in this instance), before reluctantly adopting a more methodical approach.

A significant challenge when attempting to predict future impacts of plant pests and diseases and the effectiveness of mitigation measures can be the complexity and unknown properties of interactions between multiple variables. The application of heuristics when faced with complex problems is perhaps best characterised as a coping strategy, whereby a cognitively difficult problem, or time sensitive issue, is dealt with by selecting and answering a simpler question, based upon a sub-set of (what are inferred to be) the more salient criteria.

In such saturations, recourse to heuristics can represent a strength. Under most circumstances, *they* serve us well (see Ross, 1980). Simplifying complex problems can sponsor the recognition of linkages and solutions that might have taken longer or remained undiscovered had a more systematic approach been adopted (assuming it was a viable option). However, because heuristics are approximations they have the potential to embody a range of recognised biases and errors. For example, people are prone to inductive errors, apparent in the tendency to apply old (successful *tried and tested*) solutions to new contexts (while omitting to take account of important differences), or infer familiar patterns, or trends from small, but consistent, samples (Tversky & Kahneman 1974; Kahneman & Tversky, 1981; Kahneman & Miller, 1986; Thaler & Sunstein, 2008, and others).

People (lay and expert) routinely use heuristics in order to estimate and describe probabilities (formally and informally). When asked to judge the likelihood of an event matching a pattern of phenomena they are attempting to assess the degree of fit with the wider classification. In doing so, in addition to their appreciation of relevant scientific insights, assessors are drawing upon memory and prior experience, in particular making linkages to what they believe to be equivalent situations, which may include making adjustments to what they view as the more salient features, some of which may be new or novel. In this sense heuristics might be construed as a personal library of mapped associations that are applied to inform inferential sense making. Heuristics are not just a personal coping strategy. Scientific and technical communities also tend to share certain heuristics with respect to beliefs about how phenomena operate and interact; some heuristics may simply reflect the limits of the science of the day.

The concept of cognitive bias is linked with evidence of heuristic reasoning. Human beings

can (some would suggest are prone to) exhibit an array of identifiable and predictable biases in decision making in situations of uncertainty. Heuristics and cognitive biases operate in a symbiotic manner in information processing and are exhibited by all individuals to varying degrees. This is not an area where there are marked distinctions between lay and expert groups, in fact both are susceptible to decision bias effects and prone to apply heuristics when dealing with unknown and uncertain issues that lie at, or beyond, the boundaries of their destabilised knowledge base (see Kunreuther and Gupta et al, 2010).

A significant array of biases and related effects have been identified, the most widely evidenced, and most pertinent to the current endeavour, are:

Availability bias

The ease with which outcomes can be brought to mind (recalled and visualised) increases their subjective salience and perceived liveliness (probability) of occurrence.

Key findings

- *High consequence outcomes tend to be viewed as more likely.*
- *People are prone to focus on more magnitude of outcomes than probability for catastrophic, large scale, irreversible risks.*
- *In the absence of issue specific knowledge people are prone to draw analogies with earlier high profile risks and failures of control.*
- *Vivid recall of past high consequence events can sponsor over estimate of the likelihood of their recurrence, or of analogous events occurring.*
- *Readily imagined personal and institutional consequences can cause people to focus on issues of secondary risk management.*

Effects relate to the framing of risk, consequences and solutions. The ease with which consequences can be visualised, particularly if they are widespread, catastrophic or enduring, e.g. extinction of a species, can sponsor a myopic response, such that the magnitude of consequences comes into sharp focus, to the extent that this outweighs, or diverts attention

from issues of probability; which may be low (Tversky & Kahneman, 1973; 1974, Lichtenstein et al, 1978). There are linkages with the concept *dread* (see, in particular, Slovic et al, 1982).

In the case of expert risk assessors, where an individual has a large amount of relevant experience, applying heuristics in the context of availability bias may result in a positive outcome, e.g. they may be quick to recognise a threat or identify effective mitigation measures. However, prior experience of similar events and outcomes may also have the effect of focusing on the magnitude of potential loss, and under-consideration of contextual variables, e.g. the effect of different climatic conditions, or working practices between countries. A strong focus on loss (see loss aversion and framing effects) *risks* a disproportionately cautious orientation, which sponsor over-provision in the area of risk control.

The availability heuristic appears to be sensitive to base-rate effects. For example when people are asked to assess a probability, such as *the likelihood of rain in London* described in the forecast as 'slight' their rating will very likely be higher than for an equivalent forecast (of 'slight') in Madrid. The reason for this being that they are drawing upon a heuristic that characterises perceived base rates for the two cities (see Wallsten, et al 1987). In this instance their intuition is likely substantially correct.

However, sensitivity to perceived base rates can constitute a source of bias. Windshtil and Weber, for example highlight a tendency to overestimate base rates for a specific disease due to broader perceptions of certain geographical locations being a 'hot spots' for multiple diseases, or poor infection control standards (Windshtil and Weber, 1999) (also refer to *representativeness bias* and *framing effects*).

In the context of risk management, availability effects are relevant beyond the technical properties plant pests and diseases. The ease with which outrage and dissatisfaction with g/Government and its Agencies, e.g. amongst land owners, producers, the public and other stakeholder can be brought to mind by specialists, policy makers and ministers can play a role. A central claim here, is that uncertainty over vulnerability in this area may sponsor excessive caution / risk aversion, and may divert the focus to issues of *secondary risk management*

(personal & institutional consequences, e.g. eroded trust reputational damage), rather than primary risk (pest or disease) management (see Power, 2006; Slottje et al, 2008).

In short, heuristics subject to availability bias may yield positive results in instances where an individuals' memory (personal and / or mediated) of previous events corresponds well with the objective properties and trajectory of actual events. But they may lead to overestimates if recall is amplified by strong imagery of high magnitude (catastrophic, large scale, irreversible) undesired consequences or, plausibly, underestimates if recall of analogous events is limited, e.g. no personal experience or historical precedents.

An absence of pest / disease specific knowledge has the potential to increase propensity to draw analogies with other high consequence risks that are believed to share one or more features. Unsurprisingly more recent events tend to be of greatest salience, by extension a number of closely-coupled events of a similar type tend to amplify recency bias (see Marx et al, 2007). Such effects have been widely cited as sponsoring inappropriate 'read-across' from one risk agenda to another, e.g. concern over MMR sponsoring a general reluctance to inoculate the young (see Pidgeon and Barnett, 2013). BSE impacting on beliefs regarding risks associated with veterinary medicines (Weyman & Williamson, 2007). Read-across effects probably more prevalent within lay populations, but experts are also potentially susceptible, although likely in more sophisticated ways.

In the context of expert assessment, the EFSA recommends *"It is therefore important for experts to review all relevant evidence so that it is all equally available when they are responding to questions"* (EFSA, 2014; p.23). Beyond the challenges of configuring this, this statement casts availability as an issue of knowledge management. This presents as a misinterpretation of evidence on cognitive availability and its effects, i.e. availability relates to broader, essentially affective, reactions to risk and uncertainty referenced to the characteristics of the threat, notably magnitude of consequences, and the salience of extant understandings and intuitions. Importantly, availability effects can extend to issue beyond perceptions of threats posed by pests and diseases, to secondary risk management components, e.g. the ease with which the consequences of previous institutional / regulatory failure can be brought to mind (see Power, 2006).

Anchoring and adjustment bias

Relates to the tendency to consider an options referenced to a known or established value, i.e. the tendency to focus on relative rather than an absolute values in options appraisal, generally expressed in the form of statistical probabilities or gambles

Key findings

- *People are prone to select a reference value against which they compare or estimate other values.*
- *New information tends to be reviewed with reference to a preselected anchor, rather than in absolute terms.*
- *Where knowledge is limited (to the decision maker and / or science) emotive issues and perspectives may sponsor the selection of a high or low anchor.*

Anchoring tends to take the form of individuals selecting a reference value against which they compare or estimate other values. Anchoring can impact on their appraisal of how much they should revise and adjust their original estimate to take account of new insight or additional information, e.g. new knowledge, additional data, or changes in the ratio of cases relative to sample base (see Tversky & Kahneman, 1974).

The nature of bias here is that the degree of adjustment tends to be insufficient, such that the revised judgement is biased towards the original anchor, i.e. reference to and acceptance of the anchor influences subsequent assessments. For example, assuming that a risk assessor originally estimated the impact of a risk as *'Very likely'* using the scale depicted in Table 8, new information is more likely to elicit to a minor revision to their original estimate *'Extremely likely'* or *'Likely'*, even where the new evidence would support a more fundamental adjustment. A net result of anchoring and adjustment is overconfidence in the ascribed rating range (Morgan, cited in IPCC, 2010).

Both experts and lay assessors appear to be subject to anchoring and adjustment effects. It has been suggested that selecting or providing the initial rating sponsors a sense of ownership or, perhaps more plausibly, a reluctance to admit that *you* got it wrong, particularly if this is in

the presence of peers (see Simmons et al, 2010). There is modest consensus over the causes of anchoring bias; however, evidence relating to its effects is robust (see, for example, Jacowitz & Kahneman, 1995; Strack & Mussweiler, 1997; Mussweiler and Strack, 1998).

Table 8 Example Likelihood Judgement Scale	
Likelihood of the occurrence / outcome	
Virtually certain	99% probability
Extremely likely	95%
Very likely	90%
Likely	66%
More likely than not	50%
About as likely as not	33-66%
Unlikely	33%
Very unlikely	10%
Extremely unlikely	5%
Exceptionally unlikely	1%
Source IPCC 2010	

With regard to the selection of anchors, some sources cast this in terms of being the first item assessors alight upon or are presented with (Tversky and Kahneman, 1974). However it seems likely that other variables are at play. The following is not considered exhaustive: In some instances ratings may reflect reference (which may range from *substantially accurate* to *intuitive guesstimate*) to some known quality or value (which may range from *highly appropriate* to *highly inappropriate*) ascribed to what judges consider to be an analogous risk issue (see Mussweiler and Strack, 1998). Where the issue sponsors emotive responses, a corresponding high or a low anchor may be selected (see availability). Additionally, in instances where people feel that they lack knowledge and or confidence when using a subjective rating scale they tend to engage in hedging, reflected in the selection of a rating nearer the mid-range (Oppenheim, 1966).

In the context of expert risk assessment, EFSA guidance recommends that the "*Choice of the sequence of questions in an elicitation procedure should aim to minimise anchoring, and*

should avoid introducing numerical values which might then serve as anchors." (EFSA, 2014; p.23) This is useful from the perspective of how information on risk and uncertainty is presented in the form of risk assessment procedures, but represents a partial solution from the broader perspective of anchoring effects, i.e. anchors that assessors may refer to, derived from their broader knowledge and insight. This issue is recognised by McLeod (2010). The literature makes modest reference to such effects, possibly due to the nature of the empirical studies, most of which have not involved individuals making judgements in a context in which they have established expertise. Redress of assessor reference to broader anchors is not readily resolvable.

Representativeness bias

The tendency to over-infer patterns and linkages relating to the future from a restricted sample, e.g. a small number of cases of a common type, a single or sub-set of attributes or traits, a sub-set of interactions between variables.

Key findings

- *People are prone to infer patterns from insufficient data / evidence.*
- *People tend to focus on frequencies of similar events, and underplay base rates or probability inconsideration.*
- *The time frame over which the occurrence of a small number of ostensibly consistent events can impact on perceptions of patterns in data.*
- *People can be insensitive to changes in predictive inferences that arise from changes in sample size*

In its most basic form representativeness relates to the process of inductive inference, i.e. judging the likelihood that a given object (or phenomena) relates to a particular class of objects, or that an event is the product of a recognised process. Some authors suggest that human beings are hard-wired in their disposition to seek pattern recognition.

The contiguous occurrence of a small number of sequential / related (which may in probabilistic terms be random or rare), particularly over a short time frame, tends to give rise

to what Tversky and Kahneman term '*belief in the law of small numbers*'. These authors go on to conclude that the phenomenon is amongst individuals with formal training in science, engineering and probability theory (Tversky and Kahneman, 1971; Kahneman & Tversky, 1972). A recent high profile example may be detectable in the 'string' of large scale railway accidents (Southall 1997, Paddington 1999, Hatfield 2000 and Potters Bar 2002), which led to much speculation of a trend associated with rail privatisation. Statistically, the small number of cases makes it impossible to draw firm conclusions; however the arising structural and regulatory impacts have undeniably been far reaching and enduring.

A number of studies have demonstrated that people can be insensitive to changes in base rates and base values (see, in particular, Tversky and Kahneman, 1974). Typical findings from experimental work in this area are that people tend to focus on the frequency of cases (numerator) rather than denominator values (see Yamagishi, 1997). This can be particularly problematic when making comparisons between two or more pieces of evidence based on different size samples. Other findings arising from a failure to take account of base rates, highlight a tendency to focus on frequencies, or proportions of increase, e.g. a 100% increase in cases of Ebola in the UK (currently, at least) will only affect a very small number of individuals.

Where people recognise changes in base rate, the issue tends to be not so much that they ignore this (most people have some grasp of the implications of the ratio of cases, to sample size) but that they fail to make sufficient adjustment, i.e. people can be insensitive to changes in predictive inferences that arise from changes in sample size (Fischhoff, et al, 1979).

Confirmation bias

Failure to adequately appraise new or contradictory information.

Key findings

- *Established beliefs about the nature and probability of harm can act as a filter on how new information is reviewed.*

- *When considering causality and impacts of past events people are prone to exhibit hindsight bias.*
- *Both individuals and groups appear to be susceptible to confirmation bias.*

Relates to situations where a widely held or dominant view has been formed leading to a tendency to make new evidence fit with the established view. Effects relate to individual reluctance to abandon their own internal model (see anchoring and adjustment) and a reluctance in individuals to challenge an established consensus (see Group decision biases). Once an accepted model or scenario becomes established (individually or shared) there can be a tendency to dismiss contrary information as erroneous, peripheral or unrepresentative, such that it may be disregarded or filtered out. Relatedly, there is a risk that evidence that fits the established model may assume a higher status than it should (Klorogge et al, 2007; also see Kuhn, 1972).

A further facet of confirmation bias, that may serve as a salient, or even primary, reference for new challenges is *hindsight bias*, or what has been termed *the illusion of retrospective determinism* (Bergson, cited in Garton Ash, 1996). Specifically, the tendency to exaggerate the predictability and inevitability of the course of past events in the light of hindsight. A situation in which there is a risk of failing to adequately consider how events could have turned out differently.

Unrealistic optimism bias

Overconfidence in the ability to manage, avoid or avert harm

Key findings

- *Has been identified as both an individual and a group phenomenon.*
- *Lack of real-world contextual insight, e.g. into working practices, may foster unreasonably optimistic beliefs surrounding the effectiveness of risk mitigation measures.*
- *The absence of a 1:1 ratio between risk and harm, e.g. due to chance related elements, can sponsor perceptions of invulnerability.*

- *People tend to rate their capacity to avoid harm as above average.*
- *People tend to rate themselves at below average risk compared with peers.*
- *More information can have the effect of reducing overconfidence.*

Unrealistic optimism has traditionally been cast as one of a range of biases of attribution over issues of cause and effect (see, in particular, Weinstein, 1980, 1984), but can also arise as a product of group deliberation and decision-making processes (see Group decision biases). As elsewhere, findings highlight susceptibility amongst scientists and specialists as well as lay people (see Kloprogge, et al, 2007). A notable and paradoxical finding with respect to expert risk assessors is the claim that the more information they are provided with on an unknown quantity, the less likely they are to exhibit overconfidence (Slottje et al, 2008).

By volume, the largest contribution to insights on unrealistic optimism relate to individual decision making and perceptions of personal vulnerability, notably in the lifestyle health domain (see, for example, Weinstein, 1980; 1984), supplemented by a smaller number of workplace risk (see, for example, McKenna, 1993; Rawlinson, 2004) and driver behaviour studies (see, for example, McKenna, et al, 1991). A notable contrast with the current endeavour is that these studies focus on individual volition as the basis for exposure, i.e. in contrast to exposure resulting from essentially external influences, as is the case for plant pests and diseases, and impacts that extend beyond the individual. However, the adoption of cautionary behaviour, for example on the part of importers, growers and producers, is potentially relevant in the context of risk control and mitigation.

Headline findings highlight a tendency for individuals to view themselves to be at less risk than others exposed to equivalent sources and levels of harm. Typically when asked to estimate relative vulnerability, individuals rate themselves at below average risk on a given criterion (Weinstein, 1980; 1984). A number of studies point to a related tendency towards overconfidence in the ability to recognise sources of harm and manage associated risks (Weyman & Clarke, 2003; Weyman et al, 1995).

In part, this seems likely to be attributable to the more common experience for most

individuals that exposure, does not result in negative outcomes, i.e. on most occasions many people are lucky, salient variables do not align in ways that provide a pathway for harm (see Reason, 1997) or the world does not turn out to be as risky as the experts had led us to believe. Levels of expressed optimism can also be time sensitive, i.e. perceived risk tends to be diminished when the consequences are distant rather than in the near future (see Bjorkman, 1984).

From the perspective of motivating cautionary behaviour in others, further sources of attribution bias are of potential relevance, notably self-serving and self-other biases. A general finding is that victims (including potential victims) are disposed to externalise causality, such that they are disposed to blame others, e.g. g/Government, other Nation States; other growers, producers and importers. Externalising in this way tends to inhibit motivation to adopt cautionary behaviour (see Jones & Nisbett, 1971; Ross, 1977).

Conversely, when confronted with positive outcomes people are prone to attribute this to their capacity and skill to avoid harm (whereas it may owe much good fortune), which may sponsor unrealistic optimism in their capacity to manage equivalent risks effectively in the future. Interventions to highlight and increase the salience of personal vulnerability and enhance self-efficacy represent a core assumptions of a number of psychology behaviour change models, e.g. Theory of Planned Behaviour, (Ajzen, 1991) Theory of Reasoned Action (Ajzen & Fishbein, 1980), Health Belief Model (Becker, 1974).

Although the evidence base on overconfidence is dominated by findings from research involving lay people, Morgan implies that IPCC's conclusion that scientists may be less susceptible due to "... *the[ir] greater amount of substantive knowledge they have to fall back on*" may be overly-optimistic (Morgan, cited in (IPCC 2010; p.68).

There are examples of a dislocation between the assumptions of risk assessors over effective risk control / mitigation measures and their practicability and workability in workplace contexts. This can sponsor unreasonably optimistic beliefs amongst risk assessors and risk managers regarding the effectiveness of identified controls (see, for example Weyman et al, 1995; 2005).

Loss aversion bias

Under most circumstances people are averse to loss, which can also generalise to aversion to risk and uncertainty.

Key findings

- *Under most circumstances people are averse to loss.*
- *High uncertainty, makes people reluctant to invest even when potential rewards are high.*
- *People may become risk seekers when faced with a certain loss if they do nothing.*
- *People exhibit aversion to losses that extend beyond threats such as those posed by plant pests and diseases, e.g. loss of reputation in managing sources of harm.*

Evidence from studies of investment decision making reveal that high uncertainty, makes people reluctant to invest even when potential rewards are high (see, for example, Greene et al, 2009). People generally prefer a modest *sure thing / sure win* if it is available, as opposed to a long-odds probability of a larger win, i.e. they seek certainty. As with other forms of bias, there is evidence that experts as well as laypeople are prone to exhibit loss aversion bias (see, for example, Haigh and List, 2005). However, when faced with a certain loss, e.g. species extinction, in the event that no action is taken, people are prone to select a long-odds (low probability of success) option. An analogy would be the gambler having had a bad day at the races putting his last £5 on a 100:1 outsider in the last race (Tversky and Kahneman, 1992).

Although the literature in this area is dominated by choice-based studies of financial loss and lifestyle health behaviour, in the current context, as in other public policy domains, the range and manifestation of losses to which stakeholders may be sensitive extends beyond the impacts on plants and trees. Loss aversions can operate with reference to a wide range of variables that embody uncertainty, the profile and relative emphasis of which will likely vary between stakeholders.

Of particular relevance to Government, policy delivery and regulatory functions is the

potential for aversion to losses associated with costs of expenditure on mitigation measures (absolute and relative to benefits; which may also be time sensitive) and justification of these to others; uncertainty over the effectiveness of mitigation measures, potentially extending to worry over justifying associated costs in the event of failure (poor or unmeasurable impacts); loss of trust, credibility and support from stakeholders, reputational damage (personal and corporate) (for a discussion of the impacts these secondary uncertainties on priorities and management style see Power, 2006).

Time frame biases

People prefer certain short-run to potential long run gains

Key findings

- *Subjective perceptions of the relationship between costs and benefits can be time sensitive.*
- *Options that lead to delay are generally less attractive and people engage in discounting.*
- *People tend to discount future costs and benefits more sharply, at a non-constant rate - hyperbolic discounting.*
- *People are prone to discount exponentially at a constant rate that relates to the length of the delay between investment and return.*

People generally want rewards sooner rather than later. People exhibit a general preference for certain-gains in the '*here and now*', over future benefits, particularly where the future is uncertain (see anchoring and adjustment biases). Complementary findings highlight an inhibition of caution where negative outcomes are delayed (see Bjorkman, 1984). Options that lead to delay are generally less attractive and people engage in discounting. Neoclassical economists argue that 'rational' individuals will discount future costs and benefits at a *constant* rate over time (exponential discounting). However, behavioural economists have shown that subjective perceptions of the relationship between costs and benefits can be time sensitive. Choosing short run gains over a larger reward later may not be irrational. People may prefer a sure win, or they may have an urgent need for gain. However, people do exhibit inconsistencies in their choices over gains in relation to time.

Behavioural findings indicate that individuals discount future costs and benefits at a much higher rate in the short run than in the long run. For example, an individual might prefer to receive £100 now, over £200 next year and (at the same time) the individual might prefer £200 in three years time over £100 in two years (Ainslie and Haslam, 1992). A key finding is that people tend to discount future costs and benefits more sharply, at a non-constant rate (i.e. hyperbolically). Other studies claim a more general effect, cast as quasi-hyperbolic discounting (Loewenstein and Elster, 1992. Loewenstein, G. & O'Donoghue, T. (2002) that people discount distant gains at a constant rate to reflect the presence of a delay. Additionally, they discount exponentially at a constant rate that relates to the length of the delay. In sum, the global finding is that people are disposed to greater impulsivity in the short-term.

Cultural biases

Shared disposition 'world view'.

Key findings

- *People are disposed filter information on risk uncertainty over high profile issues with reference to alignment with a range of characterizable world views.*
- *Different target audiences may have different orientations and informational needs / preferences with regard to risk and uncertainty.*
- *The mental models perspective on risk communication offers a means of charactering the perspectives of different stakeholders / different population segments.*

Although not strictly a cognitive bias, in the sense that insights arise from social anthropology and sociology rather than cognitive or behavioural science, cultural biases have been characterised as cognitive filters (Kasperson et al, 1988). The cultural theory of risk advances a typology of essentially socio-political orientations ('World views') *hierarchist, egalitarian, collectivist, individualist, and hermit* onto which different social groups (and by extension individuals and sectional interest groups) with different characterisable perspectives on risk and uncertainty can be segmented and mapped (Douglas, 1966 1982 1992; Douglas and

Wildavsky, 1982; also see Dake, 1992). Environmentalists, for example, are cast as '*egalitarian collectivists*'; characterisable as pessimistic and prone to focus on the consequences of threats to the environment and in favour of strong regulation. By contrast, *individualists* and *hierarchists* are claimed to align themselves with free market perspectives.

Detractors have essentially argued that Douglas' central thesis "*...people select certain risks for attention to defend their preferred lifestyles and as a forensic resource to place blame on other [interest] groups.*" Royal Society, 1992; P.7) aligns with common experience of a strategy people are prone to adopt when debating contentious issues (Weyman and Kelly, 1999). Other criticisms surround claims that it offers an unreasonably rigid characterisation of social differences (Pidgeon, 1996; Maris et al, 1998). Empirical evaluation of the concept has been modest but there has been notable enthusiasm for the concept (see Dake, 1991; Jenkins and Smith, 1993, Slovic et al, 1994; Slovic and Peters, 1995). Linkages to cognitive insights have been made, in which world views are cast as prepositional effects operating as cognitive filters (see Kasperson et al, 1988).

Other authors offer a more organic perspective, pointing to normative influences derived from shared experience and motivational elements, e.g. when an individual (or organisation) is motivated by factors such as moral or professional responsibility or legal liability. There are claims that the latter may sponsor under-confidence (and overly conservative, or risk averse judgements) because individuals (or organisations) find it difficult, or are unwilling to divorce their moral, professional and personal liability qualms from the assessment task (Slottje et al, 2008). It is not difficult to envisage situations in which scientific and technical risk assessors may expedience such effects when faced uncertainty. Complementary findings highlight instances where shared experience and world view (in the sense of bounded rationality- see Simon, 1957; 1996) within the scientific community can limit perspectives on casual relationships (see, for example Wynne, 1989, 1992).

Arguably a primary contribution of the world views concept contribution is that it highlights the need to consider a segmented approach to characterising stakeholder orientations on an issue and associated uncertainties, with the potential to inform thinking over engagement strategy when dealing with emotive issues. A caveat to its application is that perspectives on

harm, uncertainty and concern tend to interact with the risk issue under consideration.

There is increasing interest across government Departments and Agencies in the adoption of a segmented approach engaging with stakeholders including the public(s), particularly with respect to characterising profiles of concern, and levels of take-up of mitigation measures.

The adoption of a segmented approach rests upon the capacity to characterise extant knowledge (accurate and inaccurate), knowledge needs, and orientating predispositions of different stakeholders (including the degree to which each can be considered to possess a homogeneous perspective).

Group decision making bias

Collective perspectives on risk and uncertainty can result in more than the sum of individual perspectives.

Key findings

- *The configuration of risk assessment procedures may impact on the ratings / estimates of risk and uncertainty produced by experts.*
- *The scope for large differences in individual expert risk assessments is high - group interaction or elicitation can increase consensus but may sponsor other undesirable effects.*
- *Group deliberative processes have potential to sponsor polarization and choice shift effects.*
- *Rather than producing 'averaging effects', groups processes can lead to more extreme decisions (risk seeking or risk averse).*
- *Goal centred, isolated, highly cohesive groups that share a common world view can be prone to Group think.*
- *Group-based deliberative techniques aimed at producing consensus, e.g. Delphi, can attenuate / mask the articulation and expression of uncertainties.*

Group process insights provide a number of insights that are of potential relevance to the elicitation (and combination) of estimates of risk and uncertainty derived from the judgements by multiple experts risk assessors. There are a range of permutations with regard

to how ratings may be elicited from multiple experts, and how they might be combined. The primary focus in this section is on the former, but will have implications for the latter.

Elicitation options include variations on:

- i. individual appraisal and rating in camera;
- ii. interactive group appraisal¹²- followed and individual rating in camera;
- iii. interactive group appraisal- followed and individual rating in public;
- iv. individual rating- followed by interactive group appraisal- followed by individual reappraisal in camera;
- v. individual rating- followed by interactive group appraisal- followed by individual reappraisal in public;
- vi. interactive group appraisal- leading to whole group (consensus) rating, (possibly using formal techniques such as e.g. Delphi).

Choices over the approach to elicitation have to impact on ratings of risk and uncertainty.

Relevant insights here relates to the effects of social conformity, the effects of which are prone to vary with strength of (social) situation. Social conformity effects relate to the extent to which an individuals' behaviour is influenced by the attitudes and behaviour of others, i.e. a social comparison effect. Under most situations people seek social approval and alignment with the pack (see Asch 1951). The costs of not conforming (e.g. to reputation, potential for embarrassment and similar) can be such that individuals adjust their behaviour (or expressed opinion) to avoid such losses. From the perspective of risk assessment, where individuals are required to publicly express (and likely justify) their ratings they may be inhibited from doing so. Some might view this as a welcome feature from the perspective of achieving consensus. However, it brings with it the risk of suppressing dissent from the dominant view, which may diminish articulation of important elements.

Of the above configurations, only option (i) is free from the possibility of group conformity effects. However, option (ii) may reflect a more desirable strategy in instances where experts need to share and articulate technical insights through active debate, for example, where

¹² Face to face discussion, on-line forum, or similar

there is a need to take account of multiple perspectives and multidisciplinary insights.

Group deliberative processes can sponsor both *polarization* and *choice shift* effects.

Polarization relates to deliberative processes leading to individuals changing their view. By contrast choice shift relates to deliberative processes producing a shift (change) in the group perspective on an issue.

Of relevance to both expert and policy maker deliberations over risk and uncertainty are findings that relate to how group processes can impact on the characterisation of harm and the selection of intervention options, particularly where there is a strong drive to achieve consensus. Various, in the area of group decision making, findings highlight a tendency for deliberative groups (e.g. committees) to select more-extreme high risk options (Janis, 1972); more conservative choices (White, 1956), or averaging effects (Schachter, 1951; Cartwright and Zander, 1960) than would be the product of the sum of individual assessments (for a review see Isenberg, 1986). It seems likely that findings reflect differences in group composition, intent and features of the issues under consideration. Perhaps of note, a recent study has reported stronger group polarisation effects arising from an online dissuasion format than face to face meetings (Sia et al. in 2002).

The more fundamental, and not unintuitive, conclusion is that groups with a shared objective, such as committees, are prone produce different results than the sum of individual assessments. But clearly this does not necessarily mean that group decisions are poor decisions; rather it highlights that it can be important to consider how different configurations of eliciting risk assessment / mitigation decisions and associated judgements of uncertainty have the potential to impact on what emerges from the process.

Janis in his seminal work *Group think* (Janis, 1972; for a review of subsequent related findings see Turner and Pratkanis, 1998) provides an account of how deliberative processes, in highly focused, isolated groups, whose members share a common world view, can sponsor both over-confidence in (shared) mental models of key variables and unrealistic optimism regarding the effectiveness of chosen mitigation measure(s) (Janis, 1972).

Headline characteristics of groups that are prone to exhibit Group think are said to be: high cohesiveness; isolation from external influence / perspectives, e.g. re: evidence; low motivation to engage with systematic appraisal of evidence, strong and highly directive leadership, self-censorship; shared social identity / world view; social marginalisation or exclusion of (within group) dissenters; high stress/time pressure for results; strong external pressure to achieve results; and stereotyped negative images of non-group members (e.g. other stakeholders). Widely cited examples that are claimed to reflect the consequences of group think include: the Challenger Space Shuttle disaster and the failed CIA-sponsored counter-coup in Cuban - '*Bay of Pigs invasion*' (1961).

Strategies for reducing the propensity for group think to develop as a characteristic of organisational decision making surround being institutionally aware of its potential, and introducing formal procedural checks and balances that operate as a challenge function; where this is possible. Strategies such as rotation of Chair responsibilities and / or a programme of limited tenure for group members may also help to reduce undesirable effects. Strategically, there may also be value in giving consideration to the potential for group think to occur amongst other stakeholders involved in the risk assessment / control process.

The EFSA (2014) Guidance on Expert Knowledge Elicitation makes a number of recommendations for managing undesirable group process effects amongst expert assessors. Specifically, rather than self-managed groups, they advocate the use of a facilitator ('elicitor') to manage proceedings in order to "*...encourage the sharing of knowledge without allowing the group to be dominated by the most confident and outspoken experts,..*". Facilitators should also "*Define seed variables in a way that triggers in the experts the same heuristics as the target variables and such that they are representative of the variables of interest.*" and ... "*...recognise and correct potential biases.*" (EFSA P.33). All three of these recommendations appear desirable, however the second and third are notably more challenging, but are not group process issues per se, and it would be misleading to interpret them as such, i.e. they relate to issues of calibration and their configuration to decision architecture / anchoring effects, that can be relevant in group assessment situations, but they are not limited to or a product group process; they are also relevant to individuals as assessors. Although worthy, the EFSA recommendations on group process represent only a partial solution, in so far as,

they are limited to a sub-set of relevant group dynamics, i.e. (dominant voices), facilitation of knowledge sharing. It is important that their adoption should not sponsor overconfidence in resolution of undesirable group process effects. This issue and the effects of cognitive biases, is recognised "*...they can never be entirely removed.*" in the RR1 evaluation report (Hart, 2014).

Framing effects and bias

The manner in which issues are presented can impact upon the range of variables considered and choices in the context of uncertainty.

Key findings

- *Semantic framing of issues or options as 'gains' of 'losses' can impact on perceptions and choices.*
- *Decision architecture can impact on choices. Little is known about 'natural' (unintended) framing effects.*
- *Deep framing of choices e.g. the configuration scenarios, can impact on variables considered when making choices.*

A large body of evidence highlights how the manner in choices are framed (how risks and uncertainties are portrayed, and who portrays them) can impact upon the choices that people make.

Framing issues are relevant to the context of risk assessment performed by experts and evidence summaries submitted to ministers and policy makers. They have further relevance in the context of discourse with stakeholders, in particular, organised interest groups and motivating adoption of risk mitigation measures by landowners, growers, the public and others.

Semantic framing

Prospect theory highlights how manipulating the reference points in uncertainty scenarios

can impact on decisions. Of the array of framing effects identified¹³ the most widely evidenced are *'domain effects'*, i.e. the semantics of framing an option as the probability of a *'gain'* or a *'loss'*. When people are presented with uncertain choices of equal outcome value, casting them as a *'gain'* or a *'loss'* can impact upon their preferences in predictable ways (see, in particular, Kahneman and Tversky, & 1979; Kahneman and Miller, 1986).

In one of the classic framing experiments participants were asked to make a choice between two differentially framed uncertain options (one gain one loss of equivalent objective value) for curing a life threatening disease. Respondents showed a greater preference for the option that emphasised the *'number of lives saved'* (positive frame), compared with the alternative, *'number of lives lost'* (negative frame) Tversky & Kahneman (1981).

Similarly, framing options relating to forecasts of the effectiveness of pest or disease mitigation measures in a loss frame *"the adoption of mitigation measure X will still result in the loss of 75% of species Y*, might be predicted to elicit a different response, from *"the adoption of mitigation measures X will result in 25% of species Y being saved"*.

Cognitive framing insights are widely used in marketing and public policy domains with the overt aim of influencing the behaviour of target audiences. e.g. for smoking cessation a gain frame, such as *'having more healthy years to spend with your grandchildren'*, has been found to be more effective than the more traditional loss frame. Similarly, but perhaps less positively, in commercial advertising for labelling of foodstuffs we can observe a tendency for producers to frame products as *'X% fat free'*; rather than containing *'Y% fat'*, etc. More recent insights on framing biases have shown that sensitivity to gains and losses can vary with the issue under consideration, see Ferguson et al, 2003).

Application of framing insights are predominantly restricted to communication media, although more fundamental re-configurations of choice architecture have been attempted (see Thaler and Sunstein, 2008). The central claim here is that configuring information in ways that take account of loss and gain decision biases can nudge people to select the

¹³ See for example Kahneman & Miller 1986; Linville et al, 1987; Fagley & Miller, 1990; Lindberg & Frost, 1992.

uncertain option preferred by the communicator. Notice, that the perspective here is not one of providing neutral or objective information, but intentionally configuring the semantics in ways that play on people's propensity to make mistakes. While effects have been demonstrated in laboratory settings, the overriding picture is one of modest impacts when applied in isolation, rather than as component of a comprehensive multi-faced or layered approach (Weyman and Kelly, 1999). Semantic framing is not a silver bullet.

In instances where there is little scope for a positive frame, e.g. a choice between two unattractive options, gains are perhaps at best construed as a minimisation of losses (see Whyte, 1989).

Deep Framing

At a fundamental level the content of accounts and scenarios provided to experts (and other primary stakeholders) to characterise a pest or disease and associated risks and uncertainties, e.g. rates and manner of migration; effectiveness of mitigation measures; and may bound the range of variables that are considered. In essence, *deep framing* relates to a more profound level of choice architecture (see Thaler and Sunstein, 2008). Its configuration will likely focus attention on the authors characterisation which, if partial or incomplete, risks the omission or under-consideration of other insights. By extension, if insufficient detail or scope is provided, this may encourage assessors to draw their wider knowledge and inferences, the quality and completeness of which may be variable. The latter may reduce levels of agreement between assessors, particularly where there are marked differences in expertise and background knowledge.

Significantly less is known about how natural framing (unintended man-made, or naturally occurring choice architecture) effects impact on decision making and behaviour in the context of uncertainty. However, it seems likely that configurations will be context specific, e.g. variable depending on types of pests and associated regulatory arrangements etc. Where attempts are made to map the choice architecture relating to a specific issue, in addition recognising structural elements, it can be important to gain insight into people's beliefs and misunderstandings (mental models) about the choice architecture, in particular

aspects relating to uncertainty over consequences, as beliefs can be an important driver of decision behaviour.

While it can be important to consider how information on uncertainty is framed and how this may impact on its interpretation by others, a caveat to the overt use of message framing, with the intention of sponsoring a desired interpretation, is that if it is too transparent there is a risk that it may "...lead to suspicions of manipulation." (Fischhoff, 1995).

From the perspective of communication, message source can also operate as a framing effect, in so far as some sources may be viewed as more credible, reliable, informed or more trusted than others, and this may vary depending on the orientations of the target audience and characteristics of the issue over which there is uncertainty (see Trust and Cultural bias).

Techniques for characterising stakeholder perspectives on risk and uncertainty

It can be important to establish the extent to which the risk and uncertainty information needs, priorities and orientations of different stakeholders overlap or reflect discrete profiles. A challenge here is that this is prone to vary with respect to the pest / disease under consideration (although a categorisation of pests and diseases by shared characteristics may be possible).

Segmentation analysis permits a mapping of impacts on stakeholders as well as the role of stakeholders in the adoption of mitigation measures. This should, ideally, extend to some empirical verification / characterisation of extant knowledge, and underpinning orientations. Expert and policy maker institutions (mental models) regarding the information needs of target audiences are often found to be inaccurate (Wynne, 1989, 1992; Weyman & Williamson 2007).

Approaches aligned with the mental models approach to risk communication, developed at Carnegie Mellon University (see Morgan, 2001), have been demonstrated to offer an economical means of charactering the knowledge and understandings of different

stockholder groups, and endorsed by, amongst others the Royal Society (1992) and the HSE (2000) (a schematic summary of the general approach is provided in Figure 2).

For (known and foreseeably) contentious issues it may be useful to extend the range of variables addressed beyond technical properties of the pest or disease, to capture broader contextual elements, e.g. trust in relevant government bodies, sufficiency of regulatory arrangements, confidence in mitigation measures, and similar (Weyman and Bibby, 2005; Weyman and Williamson, 2007).

Issues of trust and credibility are of particular salience, as the impact of even the best crafted message is likely to be blunted, rejected or misinterpreted if the source has a negative profile. Again, who (institutionally) is trusted and for what types of information is likely to vary with the pest / disease under consideration, due to associations with the context in which it emerges (Pidgeon et al, 2003). Again- it may be possible to consider this issue in terms of clusters of pests or diseases with shared (physical and contextual) characteristics.

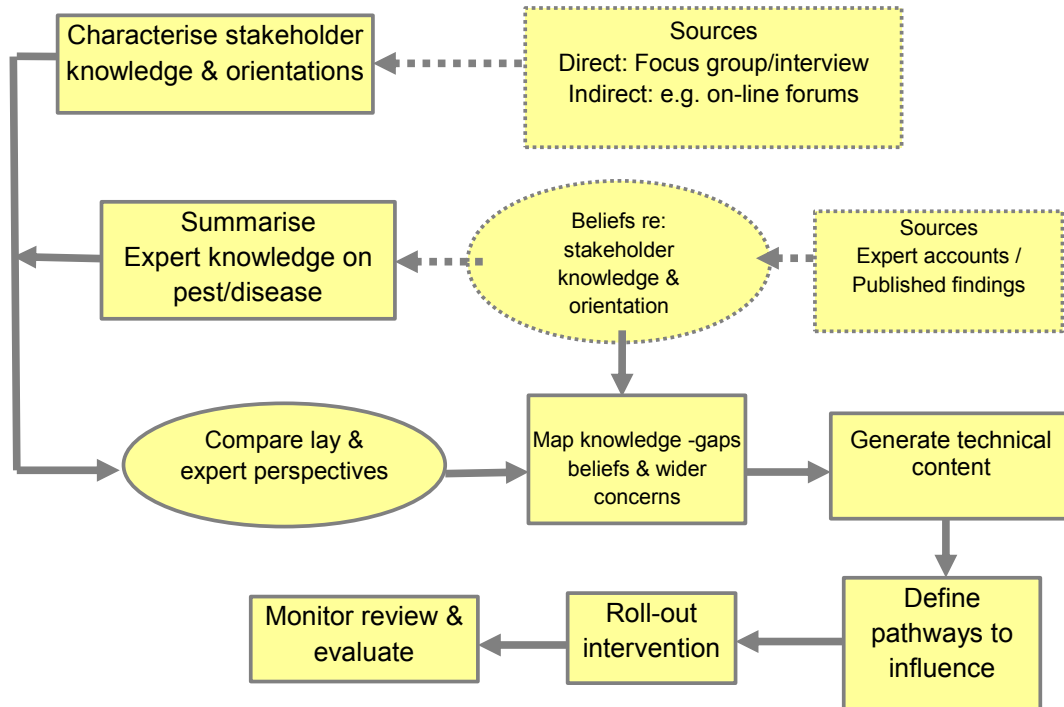


Figure 2: Characterisation of Mental Models approach for developing communication content on risk & uncertainty - after Morgan et al 1992

For high profile, high consequence pests / diseases, it is also important to keep in mind that

stakeholder information needs and orientations, once characterised, are unlikely to be set in stone, rather they are prone to evolve as the threat and institutional reactions to it unfolds (including threats that turn out to be benign). For example, during the initial identification phase the focus of concern will tend to be on uncertainties surrounding the nature and magnitude of potential consensuses. Where mitigation measures are identified, this may change to uncertainty regarding the associated costs and their effectiveness. As the issue unfolds the focus may shift to actions of government, the sufficiency of regulatory and institutional arrangements,

From the perspective of communication over uncertainty (and broader aspects) of high profile issues, there are potential gains from periodic monitoring of the profile of stakeholder orientations. Reasons for doing this are:

- To understand and recognise change in the profile of concern of key stakeholders to inform decisions over future communication strategy.
- To provide corroborative evidence of the effectiveness of communication activity with key stakeholders.

Techniques for characterising and profiling stakeholder concern have been developed and used in HSE and FSA research (Weyman and Bibby, 2005; Weyman and Williamson, 2007). Reflecting findings in the public perception of risk literature the '*Public concerns gauging tool*' was designed to profile public perspectives on a wide range of issues¹⁴.

It is presented here as illustrative of the general approach, i.e. the issues measured could have a different focus, such as different facets of uncertainty. Similarly, the choice of population segments will depend on the purpose of the endeavour and the contrasts of interest.

In the form it appears here, it has been applied to a range of issues, including passenger safety on the railways, hospital acquired infection, asbestos and veterinary medicines. The variables addressed reflect a set of headline findings from the risk literature: *dread*

¹⁴ Point estimates are generated from mean scores on subjective rating scales. In the example cited these values were derived from samples of the public (urban and rural) and DeFRA veterinary specialists.

(magnitude of consequences), *outrage*, *trust*, *non-disclosure*, and *regulation*. Each variable is a psychometric scale comprised of a set of statements, against which respondents are asked to indicate their level of agreement. Responses are aggregated to produce a fixed point value for each scale; for each group. Repeat sampling has the capacity to capture change in the profile of concern over time. Decisions over the size of the sample relate to the issue under consideration and what is to be claimed on the basis of it. Under most circumstances relatively small samples will yield useful results. Figure 3 illustrates a snapshot of differences in the profile of public concern regarding risks posed by veterinary medicines, for urban and rural samples, using radar diagrams (for a discussion of this type of display see section 9). Additionally, a panel of government veterinary experts was asked what they believed the profile of public concern to be. Notable differences are apparent between the urban and rural profiles, and both show a marked difference to the experts' mental model of public concern.

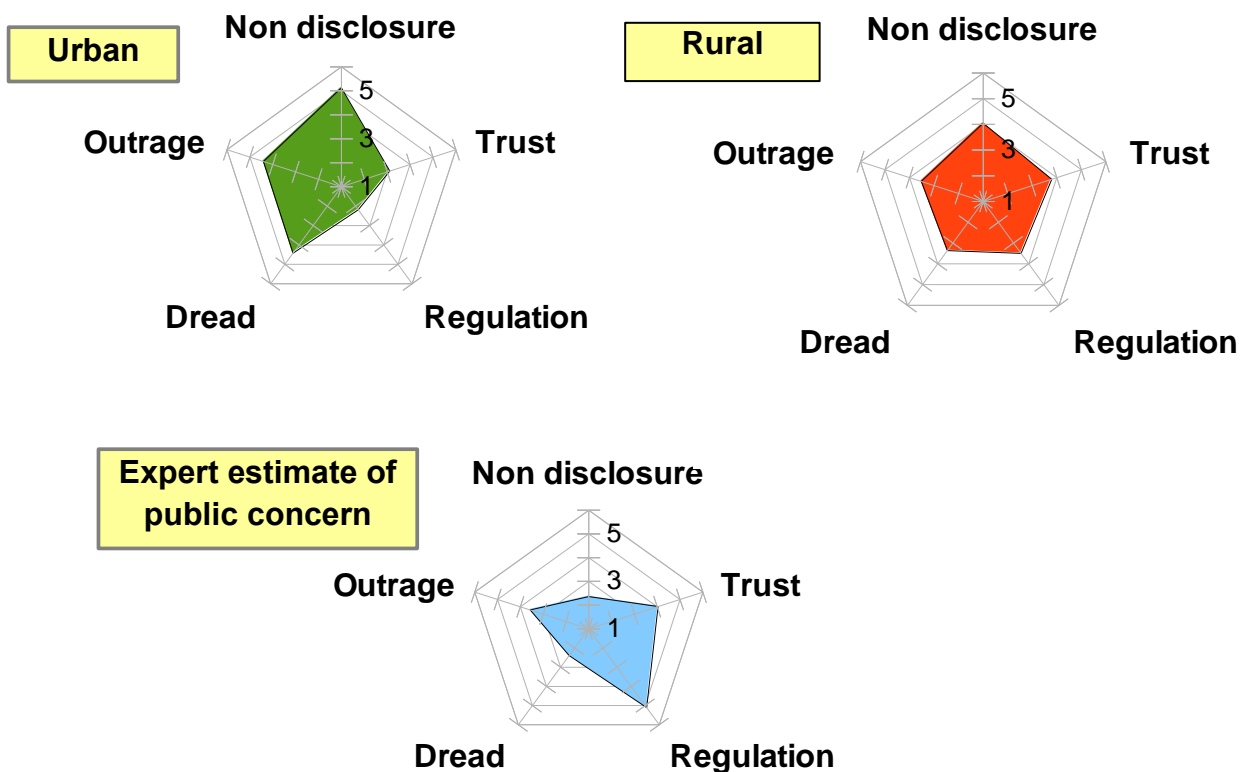


Figure 3: Characterisation of public perspectives on veterinary medicine risks

Note: Segmented v's whole population approaches to engagement

From the perspective of engagement and intervention with stakeholders arguments in favour of a segmented approach can be summarised as:

- i. Tailoring engagement strategy and information to the different perspectives and needs of different groups of individuals¹⁵ is likely to be more effective than using a one-size fits all approach.
- ii. In the context of adoption of mitigation measures identifying and targeting groups that are most malleable / amenable to influence can lead to a higher return for a given level of investment.
- iii. In the context of adoption of mitigation measures identification of high risk¹⁶ groups, e.g. by commercial activity or geographical location/region may represent the highest return on a given level of investment.
- iv. Avoiding wastage of resources though the provision of redundant information.

(Adams & White 2004)

However, knowing that different social groups or typologies of individual have different levels of knowledge, concern and information needs with respect to risk and uncertainty is of little value in itself, unless this can be mapped onto pathways to engagement and influence. For example an analysis that creates a typology based on individual differences, e.g. personality profile, or trait typologies such as '*chancers*' and '*conformists*' is of little value from the perspective of intervention (see, for example Mc Nair et al, 2004). A bespoke approach to intervention rests upon the capacity to locate relevant populations and organised interest groups geographically and / or socially, e.g. growers in the south east, and to take account of established and configurable pathways to influence¹⁷. An observation is that segmentation analyses in public policy contexts tend to lack this level of sophistication (Karanika-Murray and Weyman, 2013).

¹⁵ Including common types of organisation e.g. importers, growers, landowners.

¹⁶ A caveat is that high risk may also be hard to reach / influence, which may justify a focus on other segments that would yield higher rates of return.

¹⁷ Pathways to influence may be direct e.g. between government departments or agencies, or indirect, via surrogates, e.g. trade associations.

8. How are different presentations of uncertainty interpreted? Numbers, Numbers versus Words, Number and Words

Headline findings

- *It is safe to assume that almost all adults have a general intuitive awareness of chance, likelihood, dose-response relationships and trends.*
- *Lay audiences have been found to perform reasonably well in interpreting numerical probabilities attached to discrete events.*
- *Many people experience difficulty in comprehending the magnitude of low probability events, particularly when expressed as a decimal, e.g. .0001.*
- *P values will mean very little to most people.*
- *Reference criteria, e.g. time frame, size of base population can impact on how probabilities are interpreted.*
- *There has been much interest in verbal (semantic) expressions of uncertainty in risk assessment and communication with lay audiences. Principal limitations relate to different interpretations of their meaning and establishing their relationship to numerical expressions of probability.*
- *The number and choice of semantic anchors used in some subjective judgement scales do not appear to be closely aligned with recommendations on scale design.*
- *There is scope for misunderstanding where semantic anchors used in risk assessment scale deviate from the semantics used to express risk and uncertainty in everyday language.*
- *People (expert and lay) are prone to select more serious sounding words as expressions of probability that are 'contaminated' by their perceptions of the seriousness of consequences.*
- *The lack of precision in semantic characterisations may make the process of risk assessment appear vague and subjective to outsiders.*

The difficulty in finding effect ways to communicate uncertainty to lay audiences is not always appreciated in scientific, technical or policy communities. A variety of ways of characterising uncertainty have been developed, but most were created in scientific, technical or business contexts, essentially for internal use, such that not all are easily or appropriately interpreted by lay audiences.

A fundamental distinction, with far reaching implications for communication strategy, relates

to differences between frequentist and Bayesian perspectives. Frequentist perspectives, or perhaps more pertinently, communication material that lends *itself* to expression in these terms, is arguably the more straight-forward to deal with. Frequentist evidence benefits from the fact that it relates to historical data. Hence, at least at a superficial level, the focus for communication is on presenting this information in a manner that is accessible and pertinent to the target audience(s). Where Bayesian approaches and expert judgement are the norm, an additional challenge for communicators relates to the need for transparency over the process that underpins the estimates they produce, as well as the inherent uncertainty over these estimates, the sources of which tend to be multiple. In this context, the scope for perceptions of the credibility and trust in the source, including the potential for accusations of bias and excessive risk aversion is significantly greater, as is the scope for debate over interpretation / extrapolation from evidence.

Numerical characterisations of uncertainty

Historically, much faith has been put in numbers as a means of conveying information on environmental and technological risk and uncertainty to lay audiences, variously, as a means of allaying or stimulating concern over threats, or justifying institutional action, or inaction, associated with mitigation / control.

There is a tendency amongst scientists and technical specialists to believe that *'the numbers speak for themselves'*, to the extent that they are prone to hand over evidence in formats close to the form in which they were produced. However, where target audiences experience difficulty in their interpretation this not only undermines the impact of the data, but tends to bring with it the unhelpful effect of increasing the distance between analysts and their audience. Commentating on this Fischhoff concludes *"...experts clearly do not realise how poorly they are communicating."* (Fischhoff, 1995). More charitably perhaps, experts can experience difficulty in appreciating the needs of target audiences and in expressing their findings in accessible formats. The relevant science here is, after all, not their area of expertise. This can be very frustrating for analysts who will likely have invested a large amount of time and resource deliberating over the values presented.

An intuitive solution to the numbers issue can be characterized as *if-only target audiences had a better grasp of basic statistics, probability and related concepts the problems would go away* (Fischhoff, 1995). However, the reality is that most people possess only a limited, rather impressionistic, understanding and this is unlikely to change (Linville et al, 1987). Moreover, even the minority able to draw upon *rusty* statistical knowledge, from formal exposure in higher education, tend to perform little better than the wider population (Ibrekk and Morgan, 1987). Recognition of this has led to significant interest in finding ways to simplify numerical representations (and the language that might complement their interpretation) to enhance lay understanding.

Note: *It should be kept in mind that success in this respect in no way guarantees that the message the numbers convey will be relevant to recipients; accepted; acted upon or appropriately cited. The prize is a modest one, i.e. people correctly interpreting the information they are presented with.*

It is safe to assume that almost all adults have a general intuitive awareness of chance, likelihood, dose-response relationships and trends (that are also susceptible to an array of decision biases- see section 8). Additionally, lay audiences have been found to perform reasonably well in interpreting numerical probabilities attached to discrete events, e.g. the likelihood of rainfall (e.g. Murphey et al, 1980) although the format in which they are presented is likely to be important.

Many people experience difficulty in comprehending the magnitude of low probability events, particularly when expressed as a decimal, e.g. .0001. P values will mean very little to most people. A partial solution is to translate such expressions into a more intuitive format, e.g. 1 out of 10,000. However, people are less likely to accurately interpret the difference, or degree of change, between 1 out of 10,000 compared with 1 out of 100,000. Expressing probability as a percentage, e.g. a 10% chance of rainfall has strong intuitive appeal and is widely applied. However, there is evidence that a notable portion of lay people demonstrate limited grasp of percentages (Duff et al, 1999).

The time frame to which risk or uncertainty is anchored can also impact on how people

perceive the likelihood of harm, e.g. the chance of being injured in a car accident on any one day has been calculated to around 1 out of 10,000, whereas the chance of being injured at least twice during a lifetime of driving rises to about 1 out of 3 (Fischhoff et al, 1978). A complementary findings is that variations in the size of the reference group operates as a framing effect, e.g. 3:10 compared with 300:10,000, MacFarland and Miller (1994) conclude that people tend to focus on chance in frequency components (numerator) rather than the denominator (also see Yamagashi, 1997).

Additionally, where issues are framed as a loss, increases in the size of the reference group can increase perceptions of likelihood, such that people are prone to become increasingly pessimistic about the magnitude of impacts. However, for gain frames the reverse appears to be the case. Denes-Ray and Epstein (1994), for example, report a stronger preferences for a 9:100 chance of winning than a 1:10 chance. Such examples highlight how judgement cues from the way options are characterised can trigger framing and anchoring effects (see section 8).

Further issues arising from framing effects should be considered when charactering relative risk, particularly for dealing with low probability issues. For example, a rise in threat from 0.5% to 1%, while reflecting a 100% increase, quoting the relative magnitude of change (100%- which may represent '*hot copy*' as a media headline) is misleading in so far, as subjectively, it conveys the message of a large and significant change, whereas the probability of the event remains very low.

A widely encountered approach to representing probability is to reference an unfamiliar to a more familiar (i.e. '*known*') entity. The appeal of using comparative risk or uncertainty estimates is that the known entity can provide an anchor against which the unknown can be compared.

However, care needs to be taken in the selection of comparisons, because, as has been discussed elsewhere, people are prone to make reference to contextual components of different threats, e.g. voluntariness of exposure, trust in regulatory arrangements, magnitude of consequences. Citing the substantially lower probability of death or injury arising from rail

travel compared with travel by car did little to assuage public and institutional concern over safety on the railways following the spate of serious train accidents between 1997 and 2003. This was not because the public did not recognise differences in the probability of harm. Their rejection of the comparison was referenced to the scope for controlling exposure and perspectives on corporate responsibility (Dyball and King, 2003 and see Fischhoff, 1995).

A number of recommendations on the configuration of risk comparisons are provided by Covello et al, (1988). However, there are claims that the empirical basis for these recommendations is limited (see Morgan et al, 1992).

Verbal Characterisations of Uncertainty

There has been much interest in, and use of, semantics (words) as a means of illustrating and characterise uncertainty in the complementary domains of expert judgement in risk assessment and in communicating the findings of assessments to lay audiences (see, in particular: Zwik, et al, 1989; Budescu et al, 1988; Morgan and Henrion, 1990; Wardekker et al, 2008; Hinkel et al, 2011; Dietrick, 2012). In part the affinity for semantic characterisations reflects the widely held belief within scientific and public policy domains (backed up by some research findings, see, for example, Budescu and Wallsten, 1985; Slovic, 1995) that lay audiences experience difficulty in interpreting numbers, in particular statistical probabilities, but likely also reflects unease within public policy science over ascribing numerical values to expert judgements, in the context of limited evidence and limited certainty.

A salient issue is that, culturally, numbers are not only considered more precise than words, but once numbers are attached to entities, even where they represent best guesses, as time passes there is a tendency to treat them as fact, partly because users (people and institutions) are unsighted regarding their foundation.

It seems likely that recognition of this and its potential consequences¹⁸ may go some way towards explaining the apparent affinity for the use of language, rather than numbers, to

¹⁸ Consequences: for users of risk assessment information; and, personal and institutional reputational impacts on scientists as providers of such information

express risk and uncertainty in institutional risk assessment systems. Words perhaps also seem more closely aligned with the frequently vague and imprecise task of assessing risk, particularly in the context of deep uncertainty (Budescu et al, 1988).

A number of studies point to potential pitfalls arising from the use of semantics to express probabilities, which apply to their use by experts in formal risk assessment procedures and as a component of communications with lay audiences. Notably:

- Context has been found to impact on how verbal probabilities are interpreted.
- People are prone to be over-optimistic in assuming that others share their interpretation of a given verbal expression of amount.
- People are prone to select more serious sounding words as expressions of probability that are 'contaminated' by their perceptions of the seriousness of consequences.
- In the case of scales used to elicit adjustments of amount for plural risks, within assessor consistency tends to be significant greater than concordance between assessors, i.e. people tend to use scales consistently, but in different ways to each other (see Bryant and Norman, 1980; Brun and Teigen, 1988; Budescu et al, 1988; Patt and Schlagg, 2003- cited in Hinkel et al 2011; EFSA, 2014).

Semantics in Risk Assessment

Use of semantics in risk assessment represents a dual challenge in public policy contexts. Words used to characterise different degrees of risk and uncertainty must make sense to experts, such that they use them in a consistent and reliable manner, but their meaning and impacts on decision making also need to be transparent to stakeholders. A difficulty here is that the types of semantics commonly used in risk assessment may not readily reflect or map onto the semantics of how people describe magnitudes of risk and uncertainty in everyday language. Thus, the semantics used in risk assessment scales may not be appropriate for expressing risk and uncertainty to stakeholders.

There is a long history of semantic scales, which pre-dates empirical interest amongst psychologists and other social scientists. The Beaufort scale, for example, is designed to to

characterise different physical intensities of wind, i.e. a psychophysical scale of intensity based on 'just noticeable (or greater) difference' (see Fechner, 1860) (although current authors have no knowledge of empirical demonstration of this). Early psychophysics experiments with light intensity and similar reflect the same principles (see Gescheider, 1997). However, judgement of a psychical entity is quite different, psychologically, to the judgement of a subjective entity that does not benefit from any readily observable features. Also the Beaufort scale (and similar) is essentially finite, with a knowable maximum. The same cannot be said about entities that have unknown / unknowable maximal properties.

The Canadian NPPO risk scales system uses vignettes (rather than words) to characterise successive magnitudes. The method reflects an approach used in some experimental Health and Safety Executive (HSE) research aimed at characterising the status of risk control: a different focus but essentially following the same principles. The semantics of amount used in the HSE scales were drawn from empirical findings on judgements of amount. A fundamental difficulty with risk assessment is that it requires assessors to take account of multiple inter-related criteria for judgement multifaceted entities. The difficulties surrounding this are reflected in the thinking behind the HSE scale. It was also the reason why techniques such as paired comparisons have been found to perform better than alternative ranking techniques when attempting to produce relative rankings of multiple risks (see Cromer et al, 1984).

Apples Xs oranges

A routinely encountered approach in institutional risk assessment is the use of subjective scales to produce ratings of magnitudes or likelihood of harm and to combine the product. A fundamental issue generally accepted by those familiar with contemporary risk assessment practices is that the process involves the mathematical corruption of combining nominal elements. An arising issue is that the superficially straight-forward task of combining judgements of likelihood and consequences (and similar) embodies potential pitfalls of the type outlined below, if applied in an unsophisticated manner. Unfortunately, the use of weightings and arbitrary decision rules to address such issues have the effect of making this institutively simple process appear opaque and subjective to outsiders.

Assuming a simple High / Medium / Low (H / M / L) representation, combination rules tend to take the form of (Probability) High X (Consequences) High, or (P) Low X (c) Low = Low. Typically, numerical values are, e.g. Low = 1; Medium = 2 and High = 3 are applied (in some systems these values are weighted), such that (P) Low x (C) Medium = 2. However, a key limitation of simple multiplication is that (P) Low X (C) High = 3, produces the same numerical value as (P) High X (C) Low = 3, which under most circumstances cannot be considered equivalent. This can be problematic where the product is used to inform decisions over prioritising risks for intervention and control (see Weyman and Anderson, 1998; Gadd et al, 2003). For example, in recent years the UK Railways sector, using such as a system to produce a ranking of its top 10 hazards, led to *spillage of hot beverage* being ascribed the highest rank, i.e. it happens every day and passengers often sustain an injury as a result. Whereas, high speed train collision was ascribed relatively low rank, due to being a rare high consequence event.

It has also been claimed that scientists are prone to experience discomfort and unease when required to perform risk assessments where there is a need to reduce complex multifaceted phenomena to a single value / rating, such as 'high', 'medium or low': impact; or 'likely', 'very likely' or 'almost certain': probability. Scientists tend to be more comfortable with studying individual components of a problem and casting their findings in ways that avoid accusations of having drawn conclusions that go beyond defensible evidence (Moss & Schneider, 1997).

The limits of simple H / M / L classifications are also reached where there is a need to describe very low probabilities, or a high level of certainty. This is reflected in the development of systems with a greater array of anchors. However, increasing the number of anchors can bring its own challenges in terms of the selection of appropriate semantics and cognitive capacity (see below). Additionally, all bidirectional balanced low-high scales with an uneven number of anchors tend to suffer from ambiguity over the semantic ascribed to the mid-point, e.g. see there have been debates over the characterisation of mid-point '*medium likelihood*' used by the Intergovernmental Panel on Climate Change (IPCC), leading to its substitution with '*about as likely as not*' - see Wardekker, 2008 and MacLeod, 2010).

Inter-assessor concordance

The central claim of advocates of semantic scales is that people (in particular lay audiences) are more familiar with verbal descriptions than statistical / numerical characterisations, because they are aligned with how people talk about probability and magnitude in day-to-day discourse. It has also been suggested that semantic anchors may resolve the recognised tendency for experts to be overly precise when producing numerical estimates (and the associated risk of *over-precision* sponsoring overconfidence in estimates amongst policy makers and other stakeholders who use such information to inform their decision making).

Conversely, detractors hold that *"It is important to realise the limitations of using verbal terms rather than providing numerical values. The main problem is that people have different linguistic probability lexicons, which is to say they possess different understandings of different verbal terms, such as likely"* (EFSA, 2014; P.32)

Principal arguments against the use of semantic anchors surround:

- i. their lack of precision;
- ii. tendency to be interpreted differently by assessors (and lay people);
- iii. tendency to make the process of risk assessment appear vague and subjective to outsiders.

(Budescu et al, 1988; Wardekker et al, 2008; Hinkel et al, 2011).

The later (iii) may owe something to the degree of sophistication applied to the naming of anchors. However, the use of semantic characterisations and expressions of amount are widely applied in contentment risk assessment procedures (Gadd et al, 2003).

An observation of the EFSA's forthright condemnation of the use of semantics in risk assessment scales,

"...they are inferior to a well conducted elicitation of probability distributions and can lead to less accurate risk assessment.... qualitative estimates are particularly deficient. (EFSA Guidance on expert knowledge elicitation, 2014 P.20)

is that, paradoxically, the authors of this report advocate their use for the more fundamental issue of selecting risk assessors; using self-assessed questions that include: '*How would you rate the ease of making good judgements in your work?*' (seven point Likert scale, ranging from '*very difficult*' to '*very easy*'); similarly, '*Do you make use of a formal model for making your work judgements?*' (range '*never*' to '*always*'). Beyond the paradox, questions of this type are also prone to elicit a range of unhelpful self-serving attribution biases (see Shepperd et al, 2008).

Evidence of low levels of inter-assessor concordance using semantic scales has given rise to at least two conclusions:

- i. more appropriate semantics should be selected for the anchors;
- ii. the inherently subjectivity represents grounds for their abandonment and substitution with numbers, in particular probability estimates.

The issue of choice of semantics is potentially resolvable, in so far as recognised techniques exist for determining expressions of amount that are shared by the majority of individuals.

At this point it is perhaps useful to reflect upon the aims of the judgement task. Specifically, it is to indicate some linear change in magnitude (of some degree greater than *just noticeable difference*) between each anchor and the next. The semantic distance between anchors is therefore important, i.e. in extremis, a scale with a set of anchors of the type '*almost zero chance*', '*very little chance*', '*a small chance*', '*quite likely*', '*almost certain*' is clearly unbalanced. The distance between the anchors in terms of meaning is compressed at one end- and extended at the other, i.e. the semantics are negatively skewed. What is less clear is the extent to which widely used risk assessment scales suffer from equivalent, but likely more subtle, effects.

A substantial body of research has been dedicated to defining the semantics of judgements of amount that are: meaningful to people; have equidistant intervals of meaning equidistant (the 'distance' between one and the next is equivalent in psychophysical space); elicit reliable (reproducible) responses; and can be demonstrated to elicit high concordance between assessors, for the assessment of a given stimulus/

With regard to methods for achieving this, a range of ranking and sorting options are available. Of particular note is the method of paired comparisons (Thurstone, 1927; 1959, also see Bock and Jones, 1968), which has been found to perform well in judgements of risk and uncertainty (see Sjöberg, 1967, Cromer et al, 1984; Wallsten et al, 1986).

General guidelines on the choice of semantics and design of scales is widely available, see for example Bass and Cascio, 1974; Oppenheim (1966). An observation is that choices over the semantics and number of anchors commonly encountered in risk assessment scales do not appear to draw upon, or benefit from, these insights in large part. This is likely of limited consequence for simple scales of the *High Medium* and *Low* variety, but becomes more salient when attempting to derive a higher level of granularity. Evidence of the development of scales of six, seven, nine 10 and even 12 anchors are encountered in the risk assessment literature. For example, the scale advanced by Kraus et al (2004) has 10; the Weiss scale (cited Wardecker and van der Sluijs, 2005) has 12 and the EPPO scale, nine (source, McLeod, 2010). This contrasts with a recommended maximum of seven anchors in most guides to effective question / scale design.

As MacLeod (2010) notes, the larger the number of anchors used in semantic scales the greater the scope for and potential magnitude of differences between assessors. This is not just because of the greater scope for choice but, more fundamentally, where expressions of amount reflect too high a degree of granularity the distinction between one anchor and the next is insufficient to elicit reliable (reproducible) discrimination, i.e. the signal to noise ratio is too weak. MacLeod concludes that reducing the number of anchors has the effect of reducing the sensitivity of the scale; which is true, but needs to be considered against the potential for adding noise to ratings.

The claim that low inter-assessor concordance reflects some inherent shortcoming of semantic scales rests upon the assumption that the fault lies with the concept rather than variability between assessors. The assumption (see EFSA 2014) that expert risk assessors share a common view / perspective, such that variability in their assessments is due to shortcomings in the systems used to express their judgement, may represent a leap of faith.

As Walsten et al note, issues with semantic scales are not limited to the rigorous selection of the optimal set of anchors to achieve high consistency and high concordance. Contextual effects can lead to scales being applied differently to one issue compared with another. As Walsten et al note: "*The meanings of non-numerical probability phrases, even to an individual, are almost assuredly not fixed over contexts.*" (Walsten et al, 1986).

These authors identify a range of context sponsored sources of variability between assessors (also see Cohen et al, 1958; Pepper and Prytulak, 1974; Zimmer, 1984, cited in: Walsten et al, 1986):

- Phrases relating to periodicity of occurrence e.g. *frequency*, tend to be referenced to background knowledge of the context, i.e. availability and anchoring effects (see section 8).
- Judgements of amount e.g. *some* can be moderated by knowledge of the available quantity.
- Knowledge of base rates.
- Differences in knowledge domains.

In short, differences in the nature of specialist knowledge and degree of sophistication of assessors' mental models will inevitably, in some degree, operate as a filter and may represent a more fundamental source of variability in ratings than shortcomings (of there are numerous examples) in the scales used (also see McLeod, 2010).

As noted above, it can be important to take account the mental models of assessors. In particular, to ensure that the variables they are considering under the different headings are meaningful to them and that they apply a common set of criteria / references. There is also a *risk* that assessors will stray beyond the boundaries of what is intended by, for example, by severity and conflate this with magnitude. Also we know from cognitive bias insights that magnitude tends to impact on perceived likelihood. The most profitable perspective on resolution of this may lie in amending the assessment criteria to reflect assessor judgement processing / behaviour- rather than attempting to educate assessors to use scales 'properly'. Additionally, while potentially enhancing concordance over risk components and surrounding

uncertainties, applying assessor selection criteria designed to increase homogeneity of knowledge and shared world view may produce undesirable perspective effects that engender a shared bounded rationality and group think (see Simon, 1957; Janis; 1972; Gigrenzer and Selten, 2002).

Note: *The issue of defining appropriate expertise to conduct risk assessments comes into sharp relief in considering uncertainties over the impact of mitigation measures, as this requires the incorporation of insight and expertise that extends beyond the natural sciences. While the choice of control is a technical issue, options are constrained by relative costs and benefits, and there is routinely a need to motivate change in the behaviour of others, e.g. importers, producers, landowners, of sufficient magnitude to achieve the necessary metrics of impact. The assessment of mitigated risk cannot be divorced from consideration of the logistics of intervention. Relevant supplementary expertise includes, economics, behavioural science and communication science.*

Citing findings from the evaluation of scales used in the EPPO *Pest risk analyses scheme* (2001), MacLeod (2010) notes higher inter-assessor concordance over pests judged as posing high and low risks, but lower concordance for those occupying the mid-range. This finding is predictable, in so far as:

- i. where bi-directional scales are used, as is the case with the EPPO likelihood scale (cited in McLeod, 2010), ratings at the mid-point embody not just risk ratings that are ascribed to the mid-range in a linear sense, but are also prone to be contaminated with 'don't know' / 'uncertain' responses.
- ii. Pests judged to be at the higher end of the scale are likely to have a higher profile in the scientific community and the scientific literature, which will tend to increase their salience amongst assessors who share this experience (shared world view). Where they embody unknown elements and / or are widely viewed as high consequence this may give rise to shared availability bias (see section 8). Broadly equivalent, but opposite, effects can be predicted for the low end of the scale- sponsoring attenuation.

With regard to the design of scales, care should be taken to avoid situations where

assessment involves combining the product of unidirectional¹⁹ and bidirectional²⁰ scales (see Oppenheim, 1966). If their product is to be combined, all should consistently be either one or the other. The anchors should also, as far as possible, share a common distribution, i.e. avoiding skew. The EPPO system (cited in McLeod, 2010) is a mix, e.g. the *Adaptability* index is a skewed bidirectional scale, the *Extent* and *Frequency* scales are uni directional. Also the degree of skew in the scales is not consistent, e.g. *similarity* has only one negative, and four graduations of positive.

At one level it might be tempting to conclude that a mixed-bag of scales amounts to a source of common error- across assessors. However, the manner in which the products of scales are combined operate might have the effect of amplifying differences in systematic ways. A common, uni or bi-directional, format that avoids varying degrees of skew would be better.

Relating semantics to numbers

A conclusion within Annex 3 of *'Methods for prioritising tree and plant pests and pathogens'* was "...although the RR1 risk ratings do not have a defined quantitative meaning, they are consistent with experts' expectation that users of the RR1 have developed a good understanding of what levels of risk imply. If so, a further option for making the risk register more quantitative may be to elicit a quantitative description of this relationship from users, so that it can be used to convert ratings produced by RR1 into a quantitative measure of risk." (Hart, 2012; Annex 3, p. 41).

There are numerous examples of semantic systems used for risk assessment in which scale anchors are claimed to relate to defined numerical values, e.g. probability ranges or percentages. "*The overwhelming result is great variability in the values associated to words and large overlap among the ranges associated to various expressions.*" (Budescu et al, 1988. The IPCC system, for example has a seven point scale for eliciting judgements that a particular statement is true (see Table 9). Reportedly, similar types of scale are used to assess

¹⁹ Unidirectional scale - an incremental scale of amount e.g. *none, several, many... all*

²⁰ Bi-directional (balanced) scale - e.g. *very unlikely, unlikely, neither, likely, very likely.*

confidence in ratings, degree of consensus and amount of evidence (see Wardekker et al, 2008).

Table 9: IPCC 2007 - Judgement of uncertainty scale

extremely unlikely	<1%
very unlikely	1-10%
unlikely	10-33%
medium likelihood	33-66%
likely	66-90%
very unlikely	90-99%
virtually certain	>99%

A characteristic of many scales of this type is that it is not clear what decision criteria were applied to ascribing the mapping of numerical values onto the chosen semantics; or for that matter the criteria for the selection of the semantics for the scale anchors.

Returning to the IPCC scale, and similar instruments that attempt to map probabilities or proportions onto semantics. At initial encounter, it is not immediately apparent what the purpose of this is. If intended as a guide to assessors such that they can relate the semantics to a numerical value, it begs the question why not stick with the numerical ranges and dispense with the semantics? (see EFSA, 2014). Casting light on the thinking behind this Budescu reports that, the decision to use semantic anchors referenced to corresponding numerical (probability) anchors in the IPCC scale reflected the view that, because some of the phenomena to be assessed are hard to specify and quantify, "...being vague and elastic..[semantics] ...are consistent with wide ranges of numerical probabilities" (Budescu et al, 2009).

However, the vagueness and imprecision of semantic terms is widely recognised as their primary weakness (Wardekker, 2008; Budescu et al, 2009). It has been suggested that IPCC thinking here reflected the desire to enhance consistency in the way scales were used by assessors, summarisable as 'fixing' probability terms to semantic anchors "...makes it easier

to remember and consistent messages are perceived as more credible" (Wardekker et al, 2008).

However, if the probabilities / proportions in the IPCC are intended to reflect the semantics, and vice versa, this begs some justification, i.e. some empirical demonstration that *very unlikely*, for example, is interpreted as a 90-99% judgement of likelihood, and that multiple assessors interpret this in a common manner. In the case of the IPCC scale it is also unclear why the selected numerical ranges approximate to a normal distribution, whereas the semantics at face value *very likely* do not (see Bass et al, 1974).

Commenting on the potential for differences in how the semantics used in the IPCC scale map onto lay terminology for characterizing risk and uncertainty, only time will tell whether Wardekker et al's claim (citing Pratt and Dessai, 2005) that resolution might lie in reminding readers of risk assessment output "*...that the scale doesn't necessarily match peoples' intuitive use of language, continually reminding readers of the definitions of probability terms and comparing probabilities of different risks where appropriate*" (Wardekker et al, 2008) will prove effective in this regard.

Additionally, Wallsten takes issue with risk assessment systems that seek to supplement judgements of uncertainty with ratings of confidence in such ratings (see, for example, Hart, 2014), claiming that the former will, *naturally*, embody elements of the latter: "*Undoubtedly, people select and understand probability phrases not only as representing accounts of uncertainty but also as represented degree of confidence in that uncertainty...*" (Wallsten, et al, 1986).

Selecting empirically informed anchor words does not address the full range of objections to, or limitations of, the use of semantics scales. However, there is likely scope to enhance the degree to which they elicit consistent judgements between raters. Additionally, it may be possible to configure more defensible linkages to numerical representations of probability.

Prioritising risks and uncertainties

A core objective of risk registers is to provide a prioritisation of threats and associated risks that informs strategic thinking over intervention choices. While the focus will tend to be on threats judged as higher, as Hart appropriately notes *"...allocation of resources for further assessment and risk management should be targeted not [necessarily] on the highest risks but on the actions that offer the best return on investment (benefit / cost ratios)"* (Hart, 2014; Annex 3, P.41). In this context, *"...it has been argued that RR1 is used only to prioritise further consideration of risk and actions..."* (Hart, 2014; Annex 3, p.29), i.e. RR1 should operate a primary filter, to identify a sub-set of pests / diseases that should be subjected to deeper consideration / assessment in Risk Register 2 (RR2).

For RR2, while uncertainties regarding inherent risk remain, it is foreseeable that there will be an intensified, and relatively greater, focus on uncertainties surrounding mitigation / intervention options. The range of uncertainties over intervention choices include, but are likely not limited to:

- their relative effectiveness;
- financial costs and benefits;
- interactions with and impacts upon other species;
- the reactions of stakeholders,
- the capacity to propagate adoption of sufficient magnitude to achieve necessary metrics of impact.

As noted elsewhere, the range of relevant expertise for assessing risk and uncertainty in this domain extends beyond the natural and engineering sciences.

A criticism of RR1 is that its product is ordinal data. *"If these were accurate, they would rank risks in order of expected value but not provide information on the magnitude of difference between risks. For example, if one pest has a rating twice that of another pest, it does not mean the risk (expected value) is twice as large. Similarly, if two pests are close together on the rating scale, this does not necessarily imply a small difference in risk."* (Hart 2014; Annex

3, P.29).

A recognised limitation of subjective rating scales is that they provide no indication of the interval ('*distance*') between the entities under consideration. Additionally, as discussed elsewhere, it is important to derive insight into the degree of agreement between assessors.

Section 8 highlighted the method paired comparisons in the context of identifying suitable anchors for semantic scales (Thurstone, 1927; 1959). This technique has also been applied to producing interval scales, of relative magnitude, in the risk assessment domain (see, for example, Sjöberg, 1967; Ostberg, 1980; Cromer et al, 1984 and O'Hara et al, 2014). A notable strength of the method is its capacity to be applied to a wide range of risk management related issues, including (but not limited to): global judgements of risk for set threats, e.g. pests / diseases; their relative probability / likelihood of causing harm; their relative magnitude of harm; uncertainty over relative likelihood or magnitudes of harm; relative impacts on stakeholders; effectiveness of alternative mitigation measures; costs and benefits of alternative mitigation options, and more.

The technique is well suited to the consideration of uncertainty as it is designed to deal with judgements where the intensity of the stimulus is not known or measurable in any objective sense, i.e. unlike traditional psychophysical scales, such as the Beaufort scale where the stimulus values are known, the method is designed to deal with situations in which "*We are seeking to determine the stimulus values themselves.*" (Thurstone, 1959, p.69).

Within the risk assessment / risk management domain, the technique has been applied in the nuclear sector, forestry, mining, emergency health service and elsewhere. It is best suited to dealing with the consideration of a relative small number of entities (<10); e.g. top-tier pests/diseases, but can be extended to larger numbers. The task for assessors is procedurally very simple and involves performing a set of paired judgements, for all permutations of pairings of elements under consideration. It can be performed on paper, or electronically. It could be used to capture consensus ratings produced by groups of experts, but is more routinely completed by individuals for subsequent combination.

Its strengths can be summarised as:

- i. it produces an interval scale of relative values, i.e. differences in magnitude;
- ii. it provides a coefficient of consistency (i.e. a numerical measure to check that individual assessors are making consistent judgements);
- iii. it produces more consistent within-assessor results (reproducibility reliability) than direct ranking or subjective scales (see Cromer et al, 1984);
- iv. it provides a coefficient of concordance (i.e. a numerical measure of the degree of agreement between assessors);
- v. its product can be used to formally test differences (using parametric statistical tests) between different groups of assessors, e.g. different groups risk assessors, experts, different stakeholders, different segments of the public, etc.
- vi. it is less onerous / labour intensive than alternatives, e.g. Q sort or Delphi.

By way of example, Figure 4 summarises the output arising from the use of paired comparisons to establish relative ratings of trust in a set of UK risk management stakeholders; expressed as standard scores (Pidgeon et al, 2003). Alternative, more spatially intuitive, formats for expressing results are possible.

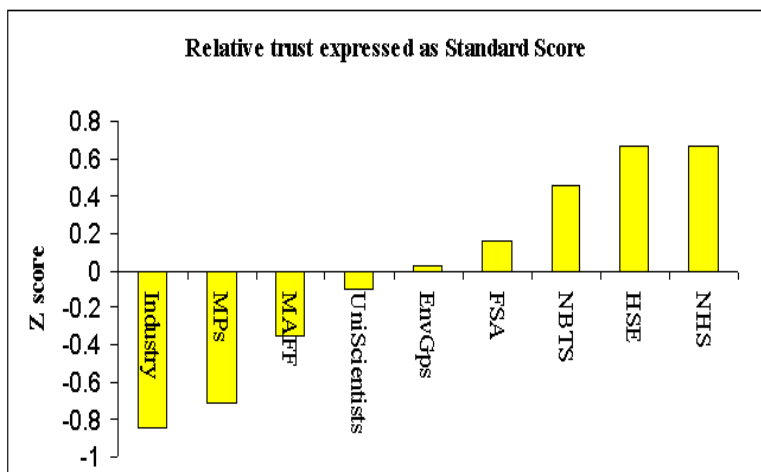


Figure 4: Relative Public Trust in Risk Management Stakeholders

Although the product of paired comparisons is an interval scale, which embodies a quantifiable metric of concordance (consensus), the intent is quite different from techniques which set out with the objective of establishing consensus, e.g. Delphi. Core limitations of

Delphi, and similar techniques relate to group process effects, some of which may be undesirable, e.g. suppression of dissent, unrealistic optimism regarding selected options (see section 7) and the tendency to mask / underplay elements over which there is uncertainty (see Yousuf, 2007).

Communicating uncertainty to stakeholders

As a number of authors have noted, the area of translating the product of risk assessments and issues over which there is uncertainty into forms and formats that are accessible to lay audiences has received modest attention.

Based on a review of empirical findings and their own empirical work Budescu et al (2009) have produced the recommendations summarised in Table 10.

Table 10 Summary of Recommendations to IPCC on Communicating Uncertainty in Risk Assessments to Lay audiences Source Buddescu et al, 2009

Make every effort to differentiate between the ambiguity of the target and underlying uncertainty. e.g. "it is very unlikely that this species will undergo a large, abrupt extinction over the next decade..."	People may disagree with the risk statement due to different interpretation of <i>unlikely</i> and / or over the magnitude of change characterisable as <i>large and abrupt</i> .
As far as possible, specify the range of sources of uncertainty relating to key events; their nature; magnitude as far as	E.g., clarify whether uncertainty is due to incomplete knowledge of pathway to harm, unreliability of measurement, and magnitude of impact.
Use both verbal and numerical values	Semantics should rely on a common stem e.g. likely*, using seven anchors.
Adjust the width of numerical ranges to match the uncertainty of target events e.g. "likely (60-80%)" or "likely (80-90%)",	Communication of uncertainty should be refined by conveying differential levels uncertainty that reflect the degree of consensus (or lack of) about the reliability and quality of available evidence.
	* Plausibly this recommendation is limited to the IPCC scale, rather than being a generic recommendation

The need to specify the nature and range, uncertainties i.e. over *what* and *why*, is underlined by the U.S. Nuclear Regulatory Commission which cautions; *"It is usually dangerous for messages to characterize the overall level of uncertainty quantitatively, as might be done by describing statistical confidence intervals. In most situations expert assessments have multiple sources of uncertainty, and statistical measures do not adequately represent the complexity of*

the analysis." (NUREG BR-0308, 2008; p.171).

Use of Graphics to Represent Uncertainty

Headline findings

- *Most forms of graphic presentation were not configured with lay audiences in mind.*
- *Familiarity within scientific graphic representations of probabilities can sponsor an under-appreciation of the difficulties laypeople may experience in interpreting them.*
- *Kite diagrams, radar diagrams and pedigree charts are used to express probabilities and uncertainties in other risk assessment/management domains.*
- *A number of the widely used graphic representations can sponsor an array of interpretation errors / biases.*
- *Box plots offer a simple intuitive format - and should represent a default choice where the limitations of the format permits.*
- *PDFs and CDF's are unfamiliar to laypeople and are conceptually unintuitive.*
- *Risk maps offer an intuitive spatial display of risk and associated uncertainties. Types of map are characterisable as: difference maps, scenario maps, ensemble maps and grid maps.*
- *The area of graphics as a measure of uncertainty would benefit for further, more extensive and comprehensive, empirical investigation.*

The use of graphical presentations as a means of conveying uncertainty to lay audiences is widespread, yet as a number of authors comment the literature on best practice in this area is notably sparse (Lipkus and Hollands 1999; Hinkel et al, 2005; Wadekker et al 2007). However, almost all commentators emphasise the pitfalls of attempting to convey too much information and failing to configure information in ways that take account of target audience needs and capacities. This situation is potentially complicated by the fact that most forms of graphic presentation were not configured with lay audiences in mind, i.e. most types have been developed for use within scientific and technical disciplines to convey meaning to individuals schooled in their interpretation. Moreover, as with numerical expressions, the arising familiarity within scientific and technical disciplines risks under-appreciation of the difficulties others might experience in interpreting them.

Less than helpfully, most communication guides make rather shallow recommendations of the type *'Information should be presented in a format that is accessible and meaningful to the target audience.'* While it is important to take account of preferences over format, Wardekker et al for example claim that policy makers have a preference for probability density functions and tables, rather than more complex representations, preferences for style of graphic are only part of the issue, representations most pertinently need to be of close fit with the questions the target audience wants answer to.

When attempting to communicate with both expert and lay audiences²¹, visual displays, such as graphs and maps embody the potential to enhance conceptual understanding (which variables are important, how they interact, or proliferate) and numerical understanding of the properties of sources of harm, risk and associated uncertainties.

As Lipkus and Hollands note, while there are exceptions, most research in this area is atheoretical (Lipkus and Hollands, 1999). Most studies set out to address ostensibly simple questions of the type, *'do graphs produce more accurate interpretations than better than numerical representations'*, *'are graphs a useful supplement to numerical representations'*, *'are some graphical representations more accurately interpreted than others'*. Few provide any rationale for the types of graphics selected for evaluation, with little or no articulation of the potential for intervening variables, e.g. quality of graphic representation, quality of supplementary information or choice of numerical representation of probability.

Kite diagrams, radar diagrams and Pedigree Charts

The NUSAP evaluation workshop on characterising uncertainty (van der Sluijs et al, 2000) explored the use of range of graphical displays to express uncertainty. Notable formats included kite diagrams, radar diagrams and pedigree charts, as well as supplementary displays such as box and whisker plots. The evaluation centred on lay interpretations of

²¹ Recognising that the needs of each may be different.

representations of expert judgement relating to the quality of science on an issue, using a five point scale (ranging from 0 = *weak*; to 4 *strong*), with semantic descriptors for each scale anchor. A core objective was to identify representations that would be effective for addressing a wide range of domains of uncertainty, e.g. empirical basis, theoretical understanding, methodological grounds, quality of proxy, value-ladenness, or validation.

The use of radar graphs and box plots, combined with the intent to use a common set of tools to assess a wide range of issues of uncertainty mirrors the remit for the Risk Gauging Tool discussed below.

The NUSAP Kite diagrams involve the use of colour (red amber green) to indicate the range of ratings given by experts (Figure 5). Wardekker, et al (2008) record that green was used to depict minimum score and red high score. If this was the case, this choice seems rather counter-intuitive, i.e. green as indicator positive / safe and red for danger is strongly culturally normed (see BS EN 61310-2:2008).

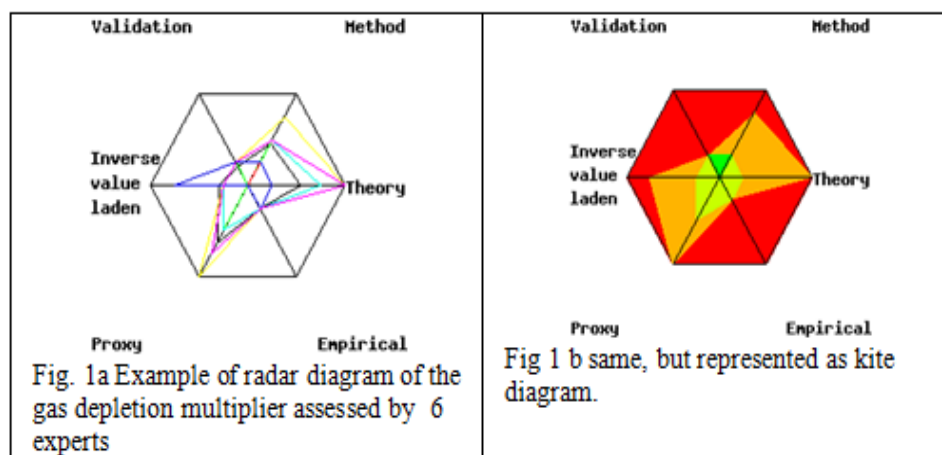


Figure 5: Example NUSAP Radar and Kite diagrams

Source: <https://proxy.eplanete.net/galleries/broceliande7/nusap-analysis-timer-energy-model>

Wardekker et al's (2008) conclusion that radar diagrams may be less suitable for non-scientists, does not chime with findings from the applications of the Risk Gauging Tool developed by the HSE (Weyman and Bibby, 2005; Weyman and Williamson, 2007), where the radar display format (supplemented by box plots and summary text) were liked and interpreted accurately by policy makers. An example of the radar diagram output from the

HSE Risk Gauging Tool is provided in Figure 6. An issue with radar diagrams is that the shape of the plot will vary depending on the order chosen for the variables. Therefore, it is important to keep this consistent when comparisons are made

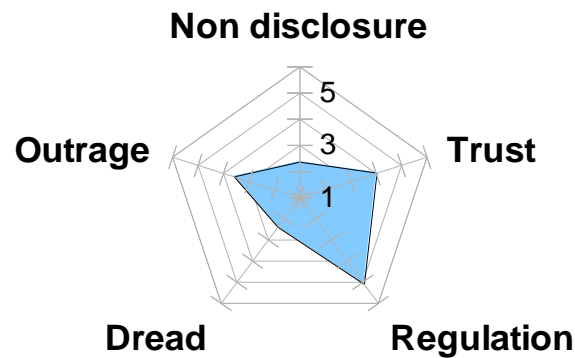


Figure 6: Example Radar Graph Source Risk Gauging Tool (Weyman and Bibby, 2005)

An alternative form of pedigree chart reported to have been trailed in IPCC workshops (Figure 7) depicts an average of expert scores using a coloured gradient from green to red (but in this instance appropriately using red to indicate a low score- negative, and green for high-positive). This display includes an option to use error bars to represent the range of aggregated expert point scores. Wardekker et al claim that this format is easier to interpret than radar diagrams and the manner in which colour is used is less likely to mislead the viewer than kite diagrams. Policy advisers were said to be "...very enthusiastic about this chart." (Wardekker et al, 2008).

Graphics and schematic representations embody the promise of providing intuitive economically efficient (time to process) ways of presenting numerical values and variable relationship information on risk and uncertainty. Lupkas and Hollands claim that graphics possess at least three desirable properties:

- they can reveal patterns that may otherwise go undetected e.g. line graphs are useful for portraying trends; pie charts and divided bar graphs proportions are well suited for depicting proportions; maps for spacial elements;
- they can speed up time taken to make process information e.g. comparison of the impact of alternative risk control / mitigation options;

- they can attract and hold more attention than text.

To the above might reasonably be added, if well designed they have the potential to enhance conceptual understandings of issues, variables and associated uncertainties, e.g. a spatial schematic adjunct to numbers potentially enhances pattern perception / recognition.

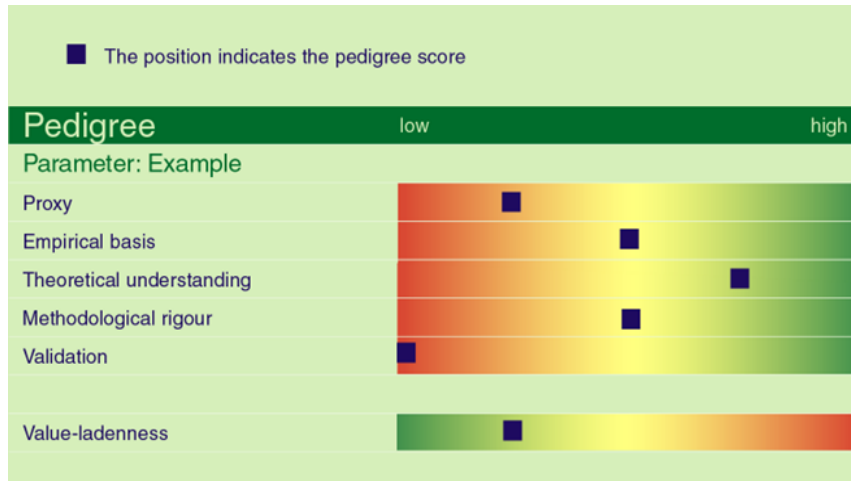


Figure 7: Example IPCC pedigree chart

Source: <https://proxy.eplanete.net/galleries/broceliande7/uncertainty-communication>

An observation is that these features may not be desirable under all circumstances, e.g. they can channel attention, such that important information in accompanying text may be missed. Additionally, people may focus on relative rather than absolute differences. Lipkas and Hollands' underline the importance of ensuring (empirically) that the interpretation placed on graphics by target audience reflects the intention of the architects, rather than taking this as a given.

Representing probability distributions

Conventional options for presenting probability distributions for a uni-dimensional uncertain entity are essentially limited to three choices: a probability density function (PDF), a cumulative density function (CDF) or as a Tukey box plot, although alternative formats have been trialed.

Although each contain broadly equivalent information, the graphics emphasise different

aspects of the probability distribution. The box plot emphasises the median and confidence intervals. The density function shows the relative probabilities of different values. Morgan and Henrion (1990) conclude that the greater sensitivity of the PDF to displaying small variations may be both a strength and a weakness, depending on the message that the communicator wishes to convey. Additionally, as a rule of thumb these authors advocate the use of the box plots, in preference to PDF's or CDF's, on grounds of simplicity, provided they provide sufficient information to capture and convey the key message.

With regard to choices over when to use a PDF or a CDF, Morgan and Henrion suggest application of the criteria summarised in Table 11, but go on to note that this should not be interpreted as privileging the use of one over another, rather they advocate the simultaneous display of both (one above the other) sharing a common horizontal axis. Possibly, somewhat optimistically in view of other evidence, these authors conclude that *"...looking at both together can help educate viewers about meaning and properties of probability distributions."* (Morgan and Henrion, 1990).

Table 11: Relative strengths of PDF and CDF's

<i>The probability density function is best for displaying</i>
the relative probability of values the most likely values (modes) the shape of the distribution (e.g. skew and kurtosis) small changes in probability density
<i>The cumulative density function is best for displaying</i>
fractiles, including the median probability of intervals, including confidence intervals stochastic dominance mixed, continuous and discrete distributions.
Source Morgan and Henrion 1990

Morgan and Henrion's conclusions in this area draw heavily upon findings earlier empirical work on lay interpretations of alternative graphical reorientations of uncertainty (Ibrekk and Morgan, 1987).

Ibrekk and Morgan (1987) set out to compare (refer to Figure 8):

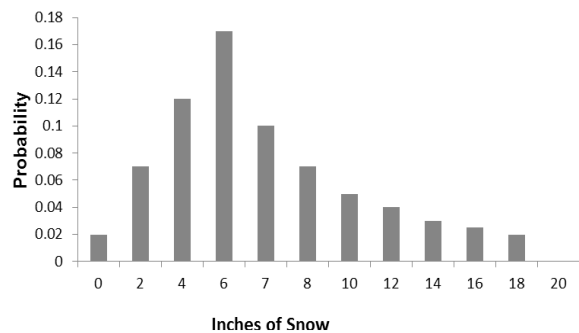
- A traditional box plot point estimate (with error bar) that spanned the 95% confidence interval (picture 1).
- A discretised version the PDF (picture 2);
- A second representation of the discretised PDF, which used a pie chart to communicate probability, where the segments span equal intervals in the uncertain quantity (picture 3);
- A conventional PDF (picture 4);
- A PDF of half its regular height, together with its mirror image (picture 5);
- A PDFs using bars of constant width that were shaded using dots (display 6) and vertical (picture 7) to display probability density.
- A Tukey box plot modified to display the mean as a fixed point and exclude maximum and minimum values (picture 8)
- A conventional CDF (picture 9).

Note: *In the interests of clarity the graphical representations used by Ibrekk and Morgan as presented in this document have been re-drawn*

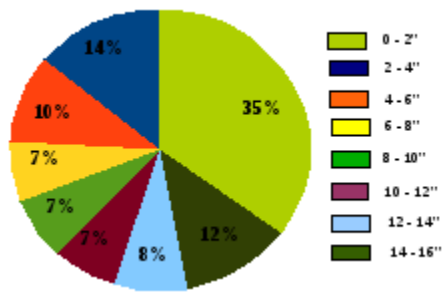
Picture 1



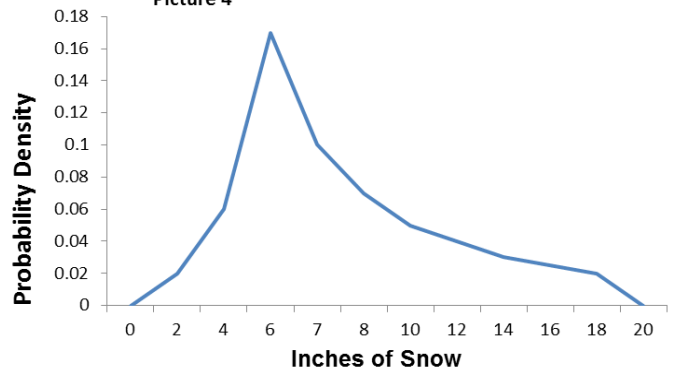
Picture 2



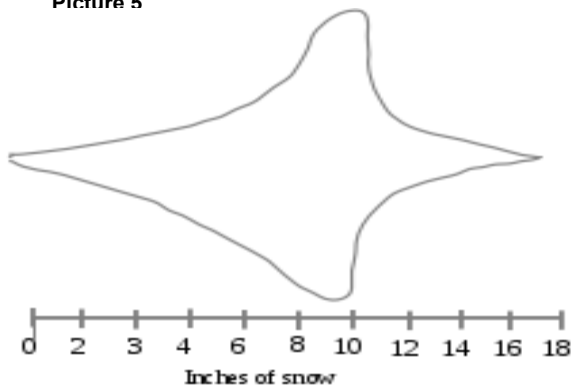
Picture 3



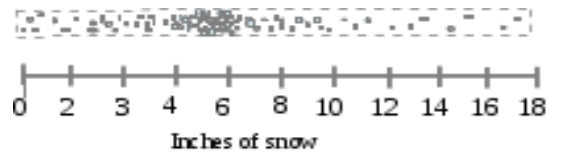
Picture 4



Picture 5



Picture 6



Picture 7



Picture 8

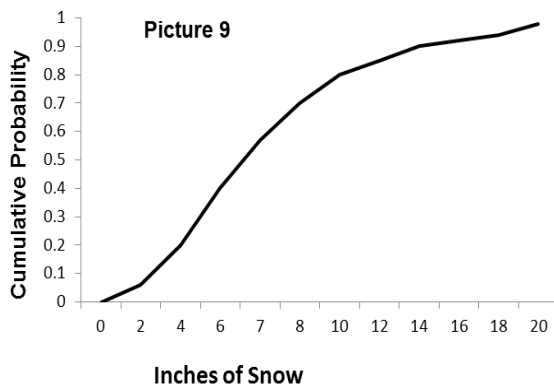
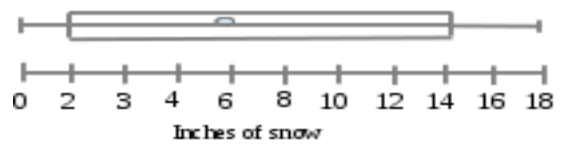


Figure 8: Alternative Representations of Probability - Ibrek and Morgan 1987.

A summary of key findings from empirical work by these authors is provided in Table 12.

Table 12: Morgan & Henrion 1990 - Summary of findings

<ul style="list-style-type: none"> • Graphs 1 & 8 which explicitly marked the mean resulted in the most accurate estimate of the mean
<ul style="list-style-type: none"> • Box plots and error bars are preferable (due to ease of interpretation), where means are the focus for communication, but are less effective for communicating probability intervals when PD is not unformed along the horizontal axis.
<ul style="list-style-type: none"> • The strategy participants used to produce a "best estimate" for graphs 2, 4, and 5 was to select the point where the curve was highest. For displays 6 and 8 they selected the point of maximum probability density.
<ul style="list-style-type: none"> • Accuracy was poorest for the CDF. 21/45 respondents produced inflated estimates of the mean. Of these 17 produced estimates that corresponded to the maximum possible value, i.e. they selected the top of the curve.
<ul style="list-style-type: none"> • The pie chart was found to sponsor confusion and misinterpretation.
<ul style="list-style-type: none"> • In displays that do not provide a strong graphical indication of density people are prone to apply a leaner proportion strategy.
<ul style="list-style-type: none"> • People show a tendency to select the mode rather than the mean in representations of PDF's
<ul style="list-style-type: none"> • The simplified PDF's (graphs 5, 6, & 7) elicited broadly equivalent accuracy, despite varying popularity, leading the authors to conclude that they can be used interchangeably.
<ul style="list-style-type: none"> • For CDF's, there are suspicions that unless clearly marked people are prone to confuse the mean with the median.
<ul style="list-style-type: none"> • PDF's should be used to support interpretations of CDF's, e.g. plotting one above the other, sharing a common horizontal scale- with the mean clearly marked on each curve²².

A complementary finding is the claim that probability density functions can lead people to focus on the tails of the display. A net result of this is said to be that the magnitude of perceived risk tends to be greater, leading to enhanced potential to elicit a disproportionately risk averse reactions (Krupnick et al, 2006).

Morgan and Ibrenk also asked their participants to provide an indication of their confidence in the accuracy of their estimates, as well as their familiarity with each type of display. This revealed highest confidence for pictures 1 and 2, and least for 5 and 9. The authors contend that high confidence for picture 2 is significant, in view of evidence of the inaccuracy of its interpretation. With regard to familiarity with the displays, in descending order participants indicated they had seen: 2 & 3 *many times before*, 1, 4 & 9, *less frequently*, 5, 6, 7 & 8 *few or no times before*. A second iteration of the study invoked the addition of written explanations

²² Lupkas and Hollands (1999) endorse the benefits of adding data points and decision point to graphics.

for each graph. The authors concluded that this produced only weak improvements²³.

These authors conclude that the performance of different displays depends upon the information that the reader is aiming to extract. At first sight their conclusion: "*Displays that explicitly contain the information that people want shows the best performance,*" (Ibrekk and Morgan, 1987) presents as no great cause for celebration. However, the authors intent is to highlight the need for communicators to have a clear appreciation of audience needs / preferences, and to supplement graphical displays with suitable text and anchors, e.g. clearly marking best estimate values, maximum and minimum and range, and similar.

Reflecting on the limited findings in this area Dessai (cited in Wardekker et al, 2005) has suggested a series of potentially useful further experiments:

- vii. A comparison of text only with text plus graphics based communication material, to establish the added value produced graphics.
- viii. Adopt a more organic approach to the selection of graphic representations adopted by Ibrekk and Morgan, though public engagement to establish display preferences, i.e. methodological a *bottom-up*, rather than a *top down* (researcher configured) approach to selecting a set of formats.
- ix. Experiment with their use as a component of scenarios, essentially characterisations of alternative futures, particularly in contexts of deep uncertainty.

A not easily resolved issue, alluded to earlier, with respect to configuring experiments to address (i) and (iii), relates to comparing two mediums (e.g. text and graphics). The deception of both will unavoidable embody variability in terms of the quality of their depiction, most acutely with regard to the configuration of text, e.g. understanding of an unintentionally poor textual characterisation may not be significantly enhanced by the best configured graphic (and vice versa).

²³ Ibrekk and Morgan provide no explanation of how they contorted for effects associated with the quality of these descriptions.

Alternative graphics for representing risk and uncertainty

Although focused on the communication of risk, rather than uncertainty per se, Lipkus and Hollands (1999) provide a useful review of alternative graphical displays, including risk ladders, line graphs, pie charts, histograms, dots and similar to indicate proportions. Two of the more relevant and novel²⁴ formats for to expressing uncertainty: risk ladder and dots are presented in Figures 9 and 10.

Note: *The reader is reminded that the volition behind Lipkus and Hollands' work was not to convey uncertainty, but to discover whether different forms of presentation impact on peoples sense of personal vulnerability to harm, i.e. it reflected a core assumption of value expectancy models of behaviour change (See Darnton, 2008) that amplifying an individual's sense of vulnerability will increase their motivation to take precautionary action, e.g. over lifestyle choices, such as smoking cessation, adopting a low fat diet and similar. However, Lipkas and Hollands (1999) do engage briefly with the commutation of uncertainty; additionally some of the evidence they cite relates to environmental issues.*

Risk ladders - are widely used to depict environmental risks. Typically, they are applied to depict a range of magnitudes, such that greater risk is depicted at higher 'rungs' on the ladder. Plural risk ladders can be used depict to indicate relative risk, or relative uncertainty, e.g. relating to best and worst case scenarios. They can also be used to engender anchoring, e.g. where the position of a novel risk is referenced to a risk already *known* to target audiences e.g. smoking versus radon exposure (see Weinstein, et al, 1993). Used in this manner they can be used to arouse concern, by conveying the message that a *new* threat is equivalent to or higher than other risks on which public policy action has been taken. Alternatively, this format can be used to indicate that a *new* threat is lower than a currently tolerated risk. There are options to enhance risk ladders with potentially useful supplementary information e.g. critical values above at which serious harm may occur, or at which mitigation measures will be applied.

Line graphs- are very widely applied as a means of indicating change over time and trend information, and benefit from an intuitive format where they relate to change over time. As with risk ladders, the format lends itself to the inclusion of relevant supplementary

²⁴ Pie chart, trend line and histogram are not included due to their lack of novelty.

information e.g. action values / points. Arguably their core strength, indicating change over time, can also be a weakness in instances where the depiction sponsors inferences of a trend based on too few data points.

Cancer Risk from Lifetime Radon Exposure	
Radon level (pCi/L)	Extra Cancer Deaths (out of 1000 people)
100	500 in 1000
40	200 in 1000
20	100 in 1000
10	50 in 1000
4	20 in 1000
2	10 in 1000
1	5 in 1000
0.5	2.5 in 1000
0.1	0.5 in 1000

Source: Lipkus and Hollands 1999.

Figure 9 - Example Risk Ladder

Dots & related formats- a number of experiential studies have used highlighted dots, (and similar, e.g. depictions of marbles in a jar), embedded in an array of dots, generally as a supplement numerical representations of probability. The idea is that the higher the relative proportion of highlighted *dots* (in this instance) to non-highlighted dots, the higher the perceived probability of an entity. Lipkus and Hollands cite claims that presentation in this format has tends to sponsor a perception of greater vulnerability (perceived threat) than numerical information alone. A series of representations of this type have also been used to convey an indication of change in probability over a defined time period.

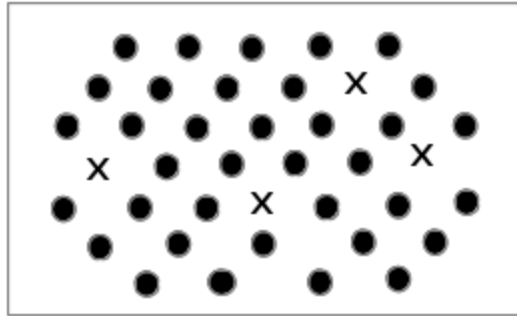


Figure 10 - X's represent 1:10 probability affected by the risk

Pie charts- are widely used, with the intent of conveying relative proportion. A strength of pie charts is that, like histograms, they represent one of the simplest, most intuitive forms of graphic representation, which most people encounter during formative education. Within the risk domain, known applications include the intent to convey comparisons between different risks, in a single chart e.g. public transport versus cars. Similarly, multiple pie charts have been used to indicate an essentially equivalent message (however, Ibrenk and Morgan (1987) caution against their use).

Histograms- like pie charts, histograms represent one of the most basic forms of graphic representation of quantity and can be considered all-but universally familiar to lay audiences. This format provides both absolute and relative values. It is foreseeable that the depiction of relative values may engender anchoring effects.

Headline findings from Lipkus and Holland (1999) are summarised in Table 13

Table 13: Lipkus and Hollands 1999 - Key findings

Risk ladders	People’s perceptions of threat are influenced by the location of the risk on the ladder- in particular people saw threat as greater for risks that were placed at the top of the ladder.
	Highlighting the exposure of different groups (or regions and other relevant demographics) on the ladder provides an indication of relative risk. The characterisation depends on whether the intent is to stimulate or attenuate concern.
	The inclusion of probabilities, e.g. number of losses arising from different levels of exposure, seems to help people understand different impacts associated with different

	levels of exposure.
	Can be configured to convey an intuitive indication of dose - response relationships.
	Helps people to anchor risk to upper and lower- bound reference points.
	Unanswered questions surround wherever the scales should be linear or algorithmic; and the range of depicted values.
Line graphs	There is evidence that some people focus on the first and last years depicted.
	There is evidence that some people are influenced by the physical size of the area under the curve.
Dots & related formats	Findings are mixed, some sources reporting that this form of density plot was a useful supplement to written information on probability, others report no enhanced effect.
Pie charts	There are reports of people misinterpreting pie charts and finding them confusing as an indicator of risk* (this finding is corroborated by Morgan Henrion, 1990; Krupnick et al, 2006).
	A pie chart displaying relative probabilities for two, or more, risks is more effective than using multiple pie charts to convey the same meaning.
Histograms	While rarely used to convey risk information, it is reported that people find this format helpful. However, evidence that they add value as a supplement to numerical risk information is inconclusive, i.e. it is not clear whether people are reacting to the quoted probability value or the height of the columns.
	* this finding is corroborated by Morgan Henrion, 1990; Krupnick et al, 2006.

Maps and Mapping

The use of maps when presenting information on known and potential infestations in a given county or region has strong intuitive appeal. The principal strengths of maps as a representation of infestation can be summarised as:

- Format that everyone is familiar with.
- They appear authoritative.
- Demonstrate differential impacts, e.g.
 - prevalence rates;
 - rate / speed of infestation;
 - effectiveness of mitigation measures;
 - rates of stakeholder adoption of mitigation measures.
- Plotted against time they can indicate change over time, e.g.
 - pattern of spread of infestation;

- rate of spread of infestation.
- Demonstrating alternative futures;
 - different scenarios of infestation (e.g. with and without mitigation; or based on alternative assumptions being true, or best versus worse case;
 - alternative mitigation measures.
- Characterising regional or seasonal differences etc. in relation to (iii)- (v) above.
- And more...

The use of colour and clear marking of key parameters helps to characterise the issue spatially. However, in common with other displays of system status, the number of colours should be kept to a minimum. Where the use of colour is intended to indicate level of threat, e.g. risk of infestation, or evidence of effectiveness of mitigation measures, the colours chosen should conform to established cultural norms e.g. red (danger / unsafe / serious / negative), yellow (caution), green (safe / stable / positive); possibly, with care, extending to varying shades (see BS EN 61310-2:2008).

However, some of the strengths of maps also embody their potential to introduce bias. Perhaps most fundamentally, because of their intuitive appeal, once cast, even if based on only the flimsiest of data, they can channel thought, such that those who view them find it difficult to think of alternatives, once presented with what may be interpreted as a definitive account. Mapped depictions of prevalence / infestation can also potentially produce undesirable anchoring effects (as well as desirable ones). It is also foreseeable that people may get drawn into the detail of the depiction, possibly at the expense of losing sight of the big picture, and / or the strength of underpinning evidence.

Of the range of different methods for representing uncertainty in maps, Visser et al (2006) characterise these using the typology presented in Table 14.

Table 14: Typology of maps for representing uncertainty

Difference maps	Useful for demonstrating aspects such as impacts / prevalence rates and similar on different regions, or a map that is based on field measurements versus a map based on a theoretically based model (e.g. of infestation) change over time etc.
Scenario maps	Useful to characterise alternative futures, e.g. status-quo v's intervention; predicted effectiveness of alternative mitigation measures, the consequences associated with different assumptions about how variables will interact. There may be benefits from presenting maps of different scenarios simultaneously, e.g. to demonstrate the relative superiority of one choice of mitigation measures over another.
<i>Ensemble maps</i>	Useful to represent uncertainties, e.g. maps produced using the same model but populated with different parameter values, i.e. variables over which there may be uncertainty or a range of predicted values.
Grid maps	Useful to provide statics relating to how certain / certain data is in each grid, e.g. that a given probability has been exceeded, aluminium or maximum values, mean and standard deviation etc.
Source: Visser et al (2006)	

Echoing a live public policy debate in the UK, Visser et al, 2006 offer the useful example of ambulance response times, to illustrate how maps can be used to inform public policy decision making over the impact of alternatives scenarios and associated uncertainties; see Box 2.

Box 2
Policy question: 'Explore the impact of reducing the number of A&E departments from 110 to 103'.
<p><i>To inform the process a 500x500m grid map was used to plot the time needed to drive from the nearest ambulance station, collect the patient and transfer them to the nearest A&E department (by extension, plausible uncertainties might surround variations in traffic densities; time taken to process admissions on arrival at different A&E departments; geographical differences in health needs prevalence rates by type).</i></p> <p><i>A component of the mapping used to answer this question is said to have involved the production of two difference maps: (i) depicting the ratio of the driving times per grid cell, and (ii) the difference in driving time per grid cell.</i></p>

Visser et al, (2006) offer a number of detailed recommendations with respect to charactering different types of uncertainty information using maps (also see Wardekker, 2012).

9. Consideration of alternative representations of uncertainty surrounding PHRR pest/disease ratings

Headline Conclusions

Risk Register Point Value plus Uncertainty Proxy Score (all pests in Register)

Strengths

Effort to develop is proportionate to the aims of the Risk Register.

Conveys an impression of objectivity through reference to underpinning science

Stakeholder involvement in selecting proxy measures might enhance ownership and acceptance.

Weaknesses

Assumes weight of knowledge diminishes uncertainty - the converse can also be the case.

Risks underplaying unknown unknowns

Subject to publication bias; funding bias and time lags between empirical work and publication date

Risks underplaying context, e.g. local conditions / practices

Not directly related to the uncertainty around risk point estimates - may inadvertently lend more credence to the point estimates than is justifiable.

Uncertainty Range Based on Estimates of Monetised Impact

Strengths

Reflects potentially strong alignment with decision making criteria applied within the policy domain, e.g. intervention choices and research investment

May chime with interests of certain stakeholders

Weaknesses

Labour intensive for retrospective application to all pests within the Risk Register - may be disproportionate / unnecessary for all pests.

Assessment of monetised values requires expertise beyond plant-pest science.

Explicit link between cost and priorities invites media attention.

May sponsor debate over values and their bases

Prone to sponsor public suspicion of partisan interests

Calculation of externalities can be unintuitive to non-experts.

Cost as a justification for non-intervention may arouse stakeholder concern.

Uncertainty range for Risk Register rating

Strengths

Focus presents as being on scientific estimates of threat.

Emphasis on natural science portrays as more neutral than when based on market costs.

Direct relationship to point estimates.

Good fit with expertise of assessors.

Weaknesses

Labour intensive for retrospective application to all pests within the Risk Register - may be disproportionate / unnecessary for all pests.

Post mitigation estimates will tend to be partial where assessor expertise is restricted to biological / technical domains - risk of underplaying wider considerations.

Potential variability in references applied by assessors to the consideration of mitigated risk.

A potentially important, and often underplayed, element in risk communication relates to what has been termed corporate body language. Routinely, stakeholder, in particular public, perceptions of risk regulatory bodies and government Departments and Agencies is fundamentally vague and impressionistic. Inferences drawn tend to be based on ad hoc / incidental acquisition of knowledge of their role, remit and track record. Most people only engage with the detail at the point where controversy emerges. The manner in which risk and uncertainty are portrayed has the potential to have impacts in this more subtle ephemeral domain of communication.

Worries that highlighting uncertainty may sponsor stakeholder concern may have some grounds, i.e. people may prefer certainty and under some circumstances are prone to being irked by uncertainty. However, the whole area of natural disease control is underpinned by its inherent uncertainty, and most people recognise this. Thus, stakeholders may be more accepting of uncertainty in this domain and its expression may serve to enhance trust. A caveat here, however, is that they will likely be less accepting of uncertainty over the adoption of mitigation measures and their effectiveness.

The following relates to the consideration of the relative merits of three alternative forms of representing uncertainty within the Risk Register, referenced to insights from social and risk management science. The alternatives considered were:

- Risk Register supplemented by an uncertainty proxy rating derived from published findings and related scientific insights.
- An uncertainty range based on monetised impacts.
- An uncertainty range referenced to the Risk Register rating.

Each is discussed in terms of its relative strengths and weaknesses.

Risk Register rating plus Uncertainty Proxy rating (all pests within the Register)

The Proxy 'score' is designed to indicate how well known the pest is, rather than assessing the uncertainty associated with point estimates in the Risk Register. Essentially, the more that is known about a pest the lower the level of judged uncertainty surrounding its impact and the probability of harm.

RR score plus Uncertainty Proxy Score (all pests in RR)

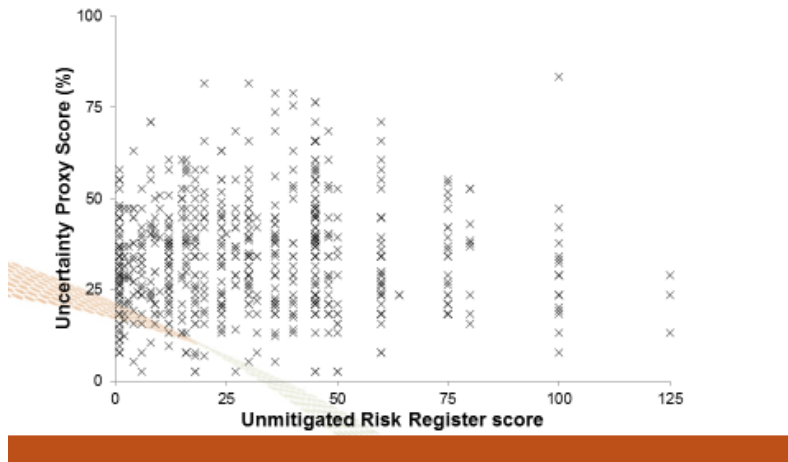


Figure 9: Graphic representation of uncertainty proxy score

Strengths

The primary strength of this method is considered to be that the effort to produce this characterisation of uncertainty for all ~700 pests might be considered proportionate to the aims and role of the Risk Register. Additionally, the fact that the product is based on published findings (in particular peer reviewed findings) may lend weight to the impression of objectivity. A solid grounding in empirical findings also reflects alignment with evidence-based approaches in other government Departments and Agencies. There is, perhaps, also scope for involving key stakeholders in the selection and review of underpinning evidence; which may bring benefits in terms of its acceptance / judged credibility.

Weaknesses

A central assumption is that uncertainty is associated with limited evidence and, by implication, more 'knowledge' will sponsor greater insight / precision, i.e. reduce uncertainty. In some instances this may be the case, however, as a number of authors have commented, more knowledge can increase uncertainty (see, for example Wardekker, et al, 2008). Additionally, there is a risk of underplaying unknown unknowns. Although this is essentially common to all three options, effects may be greater in so far as the scope may be greater due to the time-lag between discovery / empirical work and publication. Further limitations relate to the scope for a range of publication biases: notably disproportionate publication of

positive effects / relationships, particularly those that are testable in quantitative terms and achieve statistical significance (Dickersin et al, 1987 suggest a 3:1 bias), and more fundamentally those that chime with / do not contradict existing models and perspectives (see Kuhn, 1970). Relatedly, funding biases will impact on what research is commissioned, such that certain pests may attract greater empirical attention than others. Funding considerations are prone to embody reflect a broader range of considerations than the potential for biological harm, e.g. allaying stakeholder concern, economic impacts, as well as cognitive biases relating to the features of the source of harm.

A more fundamental issue, particularly when considering pests that are not currently established in the UK, relates to translating findings from other countries to the UK context, e.g. differences attributable to local climatic conditions, presence of other species, as well as man-made components, such transport / distribution differences, arboricultural, horticultural and agricultural practices, etc. i.e. there is a risk of underplaying contextual components (local conditions / practices). Implications range from drawing excessively risk averse conclusions, to unrealistic optimism.

While reference to published evidence may lend credibility to this method, its relationship to point estimates is not as intuitive as alternatives, particularly for lay audiences, i.e. it would require explanation and justification. It may also invite debate, particularly amongst organised interest groups and the media over the selection of evidence. However, this is more likely restricted to high profile / high-consequence pests over which the evidence conflicts in fundamental ways and / or chimes with established disparate discourses, e.g. tensions between mainstream and alternative science.

In terms of presentation, there is a risk of misinterpretation of proxy uncertainties, as relating to the more intuitive concept of confidence bounds surrounding point estimates.

Additionally, where stakeholders recognise that the proxy uncertainties do not relate to point estimates, this seems likely to sponsor a stronger focus on point estimates, which may result in underplaying the uncertainty surrounding these ratings, i.e. the use of proxy measures, in the absence of an expression of point estimate uncertainty may lend more credence to the point estimate than is justifiable.

Conclusions

The proxy measure offers a potentially useful supplement to Risk Register point estimates, but if used in isolation appears to be problematic from the perspective of nuancing point estimates, through highlighting bounds of uncertainty, to inform strategic thinking over risk prioritisation. A strength would seem to be its role in highlighting evidence-gaps and issues that would benefit from further research.

Uncertainty Range Based on Monetised Impact

The use of monetised values to characterise the judgements of uncertainty associated with point estimates in the Risk Register essentially relate to the translation of uncertainty estimates to quantifiable estimates of financial valuation of impact.

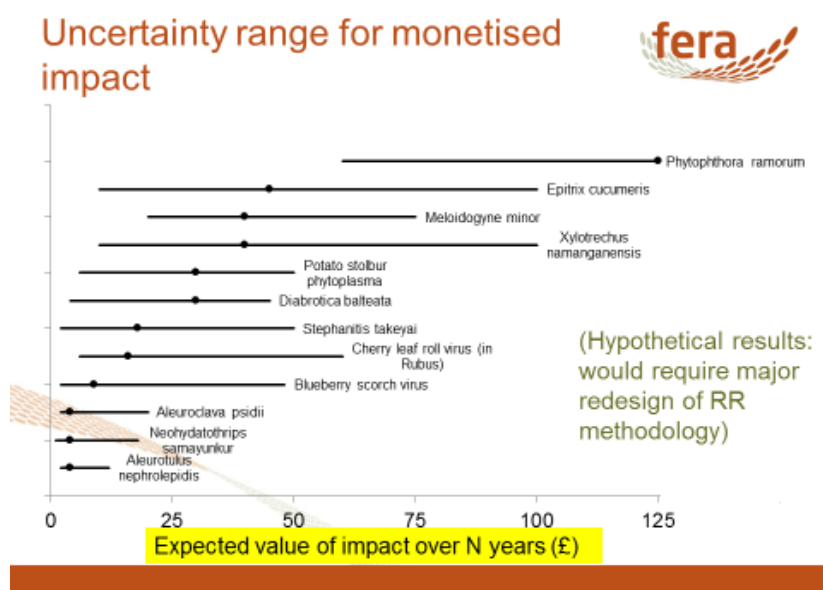


Figure 10: Graphic representation of range of uncertainty over monetised value of impacts

Strengths

Expressing uncertainty as monetised impact values has the potential to produce strong alignment with decision making criteria in policy domains, notably with regard to the consideration of intervention choices and research investment. Additionally, a transparent focus on economic impact, and intuitive linkages with this acting as a fillip for action / intervention, may chime with the interests of certain stakeholders, e.g. those whose businesses will be affected by the disease.

Weaknesses

A notable practical issue in producing cost estimates seems to be that this requires expertise beyond plant disease / pest science, i.e. the range of expertise needed to perform Risk Register assessments might need to be broadened. The calculation of externalities can be unintuitive to non-experts. This can be problematic in instances where the impact of pest / diseases have large scale highly visible detrimental impacts on the natural environment, i.e. situations which are prone to elicit strong affective responses, particularly amongst the public.

A central difficulty with monetised values is that they tend to be perceived as value laden. Specifically, they risk shifting the emphasis from the risk posed by a pest / disease (an ostensibly neutral issue rooted in science), to what tends to be seen as politically charged choices over what action should be taken. This can be particularly problematic in areas where inaction (on the part of government and its Agencies) is justified on the basis of costs being disproportionate to benefits. Monetised values are prone to sponsor suspicion of sectional interest. The public, in particular, tend to be unwilling to trade costs and benefits, tending to hold more 'binary' perspectives on when government 'should' / 'should not take action'.

An explicit link between cost and priorities invites media attention, particularly if this sponsors suspicions of inequity or serving sectional interests. It is probably reasonable to conclude that a significant proportion of the public(s) and many interest groups exhibit a suspicious disposition in relation to the actions of g/Government and / or large scale commercial interests, such that being presented with a relatively small amount of information that reinforces this tends to amplify its salience.

Monetised values can sponsor media and organised interest group debate over values and their basis. Where such debates take root, there is a risk that they may attract organised interest groups who may see such instances as an opportunity to propagate wider political agendas (world views). The ascribed values may also provide an opportunity for debate, particularly when creating estimates for non-market values. Relatedly, monetised values

imply a degree of precision which may be disproportionate to their basis and degree of consideration possible within the context of the Risk Register.

Producing monetised uncertainty estimates for all >800 plant pests / diseases within the Risk Register is labour intensive and may be considered disproportionate & unnecessary for all cases. This degree of nuancing of point estimates may be more appropriate for a sub-set of higher impact / higher profile / potentially more mitigable pests.

Conclusions

Monetised values and cost-benefit considerations will inevitably, and necessarily, play a part in the decision making process over priorities and choices regarding (in)action and intervention. However, monetised values are known to be prone to sponsoring partisan interest amongst stakeholders and the media. It may be prudent to express such values after deeper deliberation and consideration of communication issues than is possible within the practicalities of producing and maintaining the Risk Register.

Uncertainty range for Risk Register score

Uncertainty ratings produced by risk assessors to indicate the bounds of uncertainty associated with point estimates within the Risk Register.

Strengths

The principal strengths of producing uncertainty bounds that relate to point estimates are considered to be that the values relate directly to the point estimates. The inherent uncertainty surrounding pest and diseases (where they are viewed as natural phenomena rather than as the product of some man-made component), leads to strong intuitive associations with some degree of uncertainty, i.e. few will be surprised that estimates relate to a range of outcomes.

The focus on biological components, rather than broader policy considerations e.g. monetised values, potentially presents as more neutral and less likely to sponsor inferences

of partisan perspectives. In corporate body language / impression management terms, where government Departments and Agencies are perceived as raising concern / highlighting the need for action, this tends to be viewed as reflecting fundamentally altruistic (harm prevention) motives; which may represent a positive contribution to institutional trust profile.

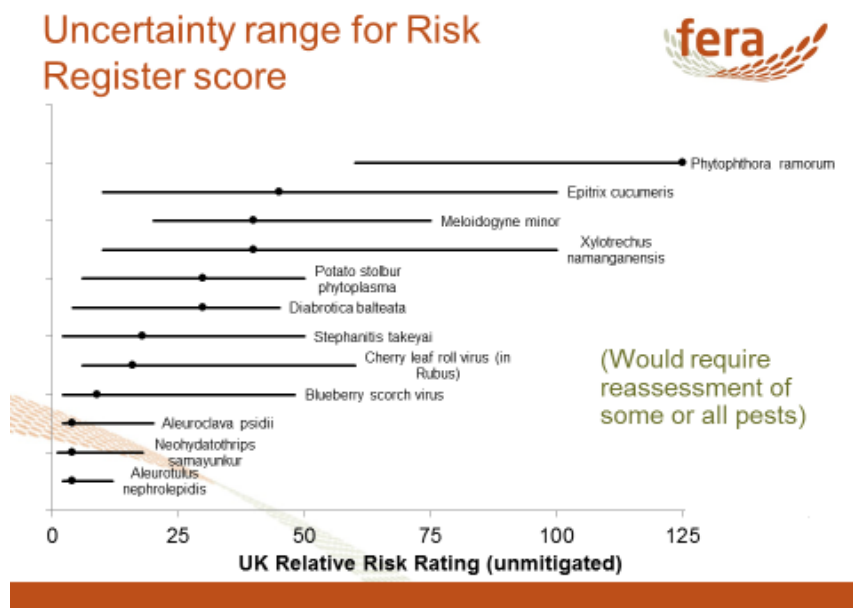


Figure 11: Graphic representation of range of uncertainty referenced to point estimates

Weaknesses

Producing uncertainty estimates for all ~700 plant pests / diseases within the Risk Register is potentially labour intensive, and there may be grounds for considering it to impractical, disproportionate & unnecessary for all cases.

Uncertainty regarding the monetised impact of mitigation estimates may be problematic as relevant considerations may lie beyond the technical expertise and influence of assessors, where this is limited to plant / pest science knowledge, i.e. options may be moderated by broader policy considerations. Implications here may range from sponsoring unreasonably optimistic to unreasonably pessimistic judgements. Differences in assessor knowledge and expertise may sponsor wide variations in estimates of uncertainty of risk and its mitigation.

Conclusions

The relationship between point estimates and uncertainty is more direct, intuitive and simpler to explain / justify than the alternatives. It is also of good fit with the expertise of risk assessors, with specialist knowledge in plant pests and diseases. This degree of nuancing of point estimates may be more appropriate for the deeper consideration of a sub-set of higher impact / higher profile / potentially more mitigable pests than the complete set of pests within the Register.

References

- Ainslie, G. and Haslam, N. (1992) Loewenstein, George (Ed); Elster, Jon (Ed), (1992). Choice over time, (pp. 57-92). New York, NY, US: Russell Sage Foundation, xxiv, 399 pp
- Ajzen, I. (1991) The theory of planned behavior. *Organizational Behavior and Human Decision Processes* 50 (2): 179–21
- Ajzen, I. & Fishbein, M. (1980) Understanding attitudes and predicting social behavior. Englewood Cliffs, NJ: Prentice-Hall.
- Arvai, J., & Campbell-Arvai, V. (2014). Risk Communication: Insights from the decision sciences. In J. Arvai & L. Rivers III (Eds.), *Effective Risk Communication*. London: Earthscan
- Asch, S.E. (1951) Effects of group pressure on the modification and distortion of judgments. In H. Guetzkow (Ed.), *Groups, leadership and men* 177–190. Pittsburgh, PA: Carnegie Press.
- Baker, R. H. A., H. Anderson, et al. (2014) The UK Plant Health Risk Register: a tool for prioritizing actions, *EPPO Bulletin* 44(2): 187-194
- Bakir, V. (2010). "Media and risk: old and new research directions." *Journal of Risk Research* 13(1): 5-18.
- Barnett, J. and G. M. Breakwell (2003). "The social amplification of risk and the hazard sequence: the October 1995 oral contraceptive pill scare." *Health Risk & Society* 5(3): 301-313
- Bass, B. M., Cascio, W. F. (1974) Magnitude estimations of expressions of frequency and amount. *Journal of Applied Psychology* 59(3); 313-320
- Becker, M.H. The Health Belief Model and Personal Health Behavior. *Health Education Monographs*. Vol. 2 No. 4.
- Bergson, cited in Garton Ash, T.(1996) In: *The Political Economy of Reform Failure*, Lundahe, M. and Wyzan, M, L, (eds) Routledge.
- Bock, R.D. and Jones, L,V, (1968) *The measurement and prediction of judgment and choice*. Holden-Day.
- Bolger, F. and G. Rowe (2015). "The Aggregation of Expert Judgment: Do Good Things Come to Those Who Weight?" *Risk Analysis* 35(1): 5-11
- Bord, R. J. and R. E. O'Connor (1992). "Determinants of risk perceptions of a hazardous waste site." *Risk Analysis* 12(3): 411-416
- Bjorkman, M. (1984) Decision making risk taking and psychological time. Review of empirical findings and psychological theory. *Scandinavian Journal of Psychology*, 67. 251-258
- BS EN 61310-2:2008 Safety of machinery. Indication, marking and actuation. Requirements for marking 28 February 2009
- Breakwell, GM. (2014) *The Psychology of Risk*, 2nd Edition, Cambridge: Cambridge University Press

- Breakwell, G. M. and J. Barnett (2001). *The Impact of Social Amplification on Risk Communication*, Contract Research Report 322/2001. Sudbury, HSE books.
- Breakwell, G., & Barnett, J. (2002). The significance of uncertainty and conflict: developing a social psychological theory of risk communications. *New Review of Social Psychology*, 2(1), 107-114.
- Bryant, G.D. and Norman, G.R. (1980) Expressions of probability in words and numbers. *New England Journal of Medicine*. 302(7); 411.
- Brun, W. and Teigen, K.H. (1988) Verbal probabilities: Ambiguous, context-dependent, or both?. *Organizational Behavior and Human Decision Processes*, 41, 390–404
- Budescu, D.V. and Wallsten, T.S. (1985) Consistency in interpretation of probabilistic phrases. *Organisational Behaviour and Human Decision Processes*. 36(3) December, 391–405
- Budescu, D.V. Weinberg, S. and TS Wallsten (1988) Decision based on numerically and verbally expressed uncertainties. *Acta Psychologica*, 68, 39–52.
- Cartwright, D., & Zander, A. F. (1960). *Group dynamics: Research and theory*. Ed. by Dorwin Cartwright and Alvin Zander. New York: Harper & Row.
- Cohen, K.; Dearnley, E.J.; Hansel; C.E.M. (1958) A quantitative study of meaning. *British Journal of Educational Psychology*, 28. 141–148; cited in: Budescu et al, 2009.
- Combs, B. and P. Slovic (1979). "Newspaper Coverage of Causes of Death." *Journalism Quarterly* 56(4): 837-843
- Cook, J.; Nuccitelli, D.; Green, S.A.; Richardson, M.; Winkler, B.; Painting, R.; Way, R. Jacobs, P.; and Skuce, A. (2012) Quantifying the consensus on anthropogenic global warming in the scientific literature. *Environmental research Letters*. May. <http://iopscience.iop.org/1748-9326/8/2/024024/article>
- Covello, V.T.; Sandman, P.M. Slovic, P. (1988) *Risk Communication, Risk Statistics, and Risk Comparisons: A Manual for Plant Managers*. Washington, DC: Chemical Manufacturers Association.
- Cromer, MK ; Seaver, D.A. ; Stillwell, W.G. and Gaddy, C.D. (1984) *Generating Human reliability estimates using expert judgment*. Vol2; The Maxima Corp, Maryland, US Nuclear Regulatory Commission. Contract Report NUREG/CR-3688/2
- Dake, K. (1991) Orienting dispositions in the perception of risk: an analysis of complementary world views and cultural biases. *Journal of cross-cultural psychology*. 22; 61-82
- Dake, K. (1992) *Myths of Nature: Culture and the Social Construction of Risk*. *Journal of Social Issues* 48(4) 31-47
- Darnton, A. (2008) *Reference Report: An overview of behaviour change models and their uses*. GSR Behaviour Change Knowledge Review. http://www.civilservice.gov.uk/wp-content/uploads/2011/09/Behaviour_change_reference_report_tcm6-9697.pdf
- Defra project: TH0120: Food and Environment Research Agency
- de Loe, R. C. (1999). "Dam the news: Newspapers and the Oldman River Dam project in Alberta." *Journal of Environmental Management* 55: 219-237

- Department of Health (1998) Communicating About Risks to Public Health: Pointers to Good Practice. Revised Edition. London: The Stationery Office
- Denes-Ray and Epstein (1994) Conflict between intuitive and rational processing. When people behave against their better judgement. *Journal of Personality and Social Psychology*. 66, 819-829.
- Dickersin, K.; Chan, S.; Chalmers, T. C.; et al. (1987). "Publication bias and clinical trials". *Controlled Clinical Trials* 8 (4): 343–353.
- Dietrick, S.(2012) Evaluating impact visualisation of uncertainty for public policy decision support. Proceeding AutoCarto Columbus Ohio USE, September 16-18.
- Douglas, M. (1966) Purity and Danger, analysis and concepts of polluyino and taboo. Cited in: J. Gabe Helath Medicine and Risk, Sociological approaches. Blackwell 1995.
- Douglas, M. (1992) Risk and blame. Routledge, London.
- Douglas, M. and Wildavsky, A, (1982) Risk and culture an essay on the selection of technological and environmental dangers. Berkley, University of California Press.
- Duff, A.R.; Robertson, I. T.; Phillips, R.A.; Marsh, T.; and Weyman , A.K> and Cooper, M.D. (1999) Improving safety on construction sites by changing personnel behavior. Phase 2. HSE Books, Bootle.
- Dyball, M. and King, H. (2003) Public dialogue on train protection Health and Safety Executive Research Report 055.
- Earle, T. C. and M. Siegrist (2006). "Morality information, performance information, and the distinction between trust and confidence." *Journal of Applied Social Psychology* 36 (2): 383-416.
- Eldridge, J., Kitzinger, J., Philo, G., Reilly, J., Macintryre, S., & Miller, D. (1998). The re-emergence of BSE: the impact on public beliefs and behaviour. *Risk and Human Behaviour Newsletter*, 3, 6-10;
- EFSA European Food Safety Authority (2014) Guidance on Expert Knowledge Elicitation in Food and Feed Safety Risk Assessment, *EFSA Journal* 2014;12(6):3734
- Fechner, G.T. (1860) Elements of Psychophysics.
- Ferguson, E; Bibby, P; Leavis, J. & Weyman, A.K (2003) 'Effective design of workplace risk communication material' HSE Contract research report No: RR.093; HSE, Books; HMSO.
- Fischhoff, B.; Slovic, P.; Lichtenstein, S.; Read, S.; and Combs, B. (1978) How safe is safe enough? A psychometric study of attitudes towards technological risks and benefits. *Policy Sciences*. April 1978, 9(2); 127-152.
- Fischhoff, et al, (1979). cited in: Hazards Vulnerability and Environmental Justice S.L. Cutter Earthscan, Oxford, 2006.
- Fischhoff, B, (1995) Risk perception and communication unplugged. Twenty years of process. *Risk Analysis* 15(2); 137-145.
- Fischhoff, B., & Davis, A. L. (2014). Communicating scientific uncertainty, *Proceedings of the National Academy of Sciences*, 111(Supplement 4), 13664-13671

- Fox, C. R., & Irwin, J. R. (1998) The Role of Context in the Communication of Uncertain Beliefs, *Basic and Applied Social Psychology*, 20(1), 57-70
- Freudenburg, W. R. (1993). "Risk and Recreancy- Weber, the Division-Of-Labor, and the Rationality of Risk Perceptions." *Social Forces* 71(4): 909-932
- Freudenburg, W. R., et al. (1996). "Media coverage of hazard events: Analyzing the assumptions." *Risk Analysis* 16: 31-42.
- Frewer, L. J., et al. (1993). "Modelling the media: the transmission of risk information in the British quality press." *IMA Journal of Management Mathematics* 5 (1): 235-247
- Frewer, L. J., et al. (2002). "Public preferences for informed choice under conditions of risk uncertainty." *Public Understanding of Science* 11(4): 363-372
- Frewer, L. (2004) The public and effective risk communication. *Toxicology Letters*. 149(1-3); 391–397
- Frewer, L. J., Hunt, S., Brennan, M., Kuznesof, S., Ness, M., & Ritson, C. (2003). The views of scientific experts on how the public conceptualize uncertainty. *Journal of Risk Research*, 6(1), 75-85
- Frewer, L., & Salter, B.(2007). Societal trust in risk analysis: Implications for the interface of risk assessment and risk management. In M. Siegrist, T. C. Earle & H. Gutscher (Eds.), *Trust in cooperative risk management: Uncertainty in scepticism in the public mind* (pp. 143-158).
- Friedman, S. M., et al. (1987). "Reporting on Radiation: A Content Analysis of Chernobyl Coverage." *Journal of Communication* 37(3): 58-67.
- Gadd, S.; Keeley, D.; Balmforth, H. (2003) Good practice and pitfalls in risk assessment. HSE Contract research report No: RR.151; HSE, Books; HMSO.
- Gescheider G (1997). "Chapter 1: Psychophysical Measurement of Thresholds: Differential Sensitivity". *Psychophysics: the fundamentals* (3rd ed.). Lawrence Erlbaum Associates.
- Gigrenzer, G. and Selten, R. (2002) *Bounded rationality- the adaptive toolbox*. MIT Press.
- Government Office for Science (2014) *Innovation: Managing risk, not avoiding it* <https://www.gov.uk/government/publications/innovation-managing-risk-not-avoiding-it>
- Gray, G.M., Allen, J.C., Burmaster, D.E., Gage, S.H., Hammitt, J.K., Kaplan, S., Keeney, R.L., Morse, J.G., North, D.W., Nyrop, J.P., Stahevitch, O.A & Williams, R. (1998) Principles for Conduct of Pest Risk Analyses: Report of an Expert Workshop. *Risk Analysis*, 18 (6), 773-780
- Greene, D.L; German, J.; Delucci, M.A. (2009) Fuel economy. The case fore reducing climate failure impacts in the transportation sector. Cited in: *Climate Change 2014: Mitigation of Climate Change*. Cambridge University Press.
- Griffin, R. J., et al. (1995). "The Effects of Community Pluralism on Press Coverage of Health Risks from Local Environmental Contamination." *Risk Analysis* 15(4): 449-458.
- Grove-White, R., et al. (1997). *Uncertain World: Genetically Modified Organisms, Food and Public Attitudes in Britain*. Lancaster University, Centre for the Study of Environmental Change: 1-61.

- Guimarães P. A. and Quintana, C.S. (2002). From Technocratic to Participatory Decision Support Systems: responding to the new governance initiatives. (2002). *Journal of Geographic Information & Decision Analysis*. 6(2); 95-107.
- Hart, A. (2014) Methods for prioritising tree and plant pests and pathogens
- Haigh M.S. and List, J.A. (2005) Do Professional Traders Exhibit Myopic Loss Aversion? An Experimental Analysis. *The Journal of Finance* 60(1); 523-534
- Hale, A. and Glendon, I. (1987) Individual Behaviour in the face of danger. *International safety series volume 2*
- Heberlein, T.A. and Stedman, R.C. (2009) Socially amplified risk: attitude and behaviour change in response to CWD in Wisconsin deer. *Human Dimensions of Wildlife: An International Journal*, 14:5, 326-340
- Hinkel, J. (2011) Indicators of vulnerability and adaptive capacity: towards a clarification of the science policy interface. In: *Global Environmental Change* 21, 198–208.
- HSE (2001) Reducing risks, protecting people - R2P2; HSE's decision-making process. Health and Safety Executive. <http://www.hse.gov.uk/risk/theory/r2p2.pdf>
- Hughes, E., J. Kitzinger, and G. Murdock. 2006. The media and risk. In *Risk in social science*, ed. P. Taylor-Gooby and J.O. Zinn, 250–70. Oxford: Oxford University Press.
- Ibeck, H. and Morgan, M.G. (1987) Graphical communication of uncertain quantities to nontechnical people. *Risk Analysis* 7; 519-529.
- Isenberg, D.J. (1986) Group polarization: A critical review and meta-analysis. *Journal of Personal and Social Psychology*, 50(6), 1141-1151.
- Jacowitz, K.E., & Kahneman, D. (1995). Measures of anchoring in estimation tasks. *Personality and Social Psychology Bulletin* 21; 1161-67
- Janis, I.L. (1972) *Victims of groupthink*. Boston Houghton Mifflin, Cited in I.L. Janis *Groupthink* Boston, Houghton Mifflin 1982.
- Jenkins-Smith, H.C.V. (1993) Nuclear imagery and regional stigma. Testing hypotheses of image and valuation. Nevada technical report University of New Mexico, Institute of public policy.
- Jensen, K., & Sandøe, P. (2002). Food Safety and Ethics: The Interplay between Science and Values. *Journal of Agricultural and Environmental Ethics*, 15(3), 245-253
- Joffe, H. (2008). "The Power of Visual Material: Persuasion, Emotion and Identification." *Diogenes* 55(1): 84-93.
- Johnson, B. B., & Slovic, P. (1995) Presenting uncertainty in health risk assessment: initial studies of its effects on risk perception and trust. *Risk Analysis*, 15(4), 485-494.
- Johnson, B. B. and P. Slovic (1998). Lay views on uncertainty in environmental health risk assessment. *Journal of Risk Research* 1(4): 261-279
- Jones, E.E. & Nisbet, R.E (1971) The actor and the observer. Divergent perceptions of the causes of behaviour. in E.E. Jones H.H. Kwily, R.E. Nisbett; S. Valins; & B. Weiner (1972) *Attribution perceiving the causes of behaviour*. General learning press.

- Kuhn, K. M. (1997). "Communicating uncertainty: Framing effects on responses to vague probabilities." *Organizational Behavior and Human Decision Processes* 71(1): 55-83
- Ibrekk, H and Morgan, M.G. (1987) Graphical communication of concertina quantities to non-technical people. *Risk Annalists* 7(4) 519-529
- Kahneman, Daniel; Tversky, Amos (1972). Subjective probability: A judgment of representativeness. *Cognitive Psychology* 3 (3): 430–454.
- Kahneman, Daniel; Tversky, Amos (1973). "On the psychology of prediction". *Psychological Review* 80 (4): 237–251
- Kahneman, D. & Miller, D. (1986) Comparing reality to its alternatives. *Psychological Review* 93(2); 136-153
- Kahneman, D. & Tversky, H, (1981) The framing effect and the psychology of choice. *Science* 211; Jan. No 4481; 453-458.
- Kahneman, D. (2011) *Thinking: Fast and Slow*. Farrar, Straus & Giroux.
- Kasperson, R.; Renn, O.; Slovic, P.; Brown, G.; Emel, J.; Gonet, R.; Kasperson, J. and Ratick, S. (1988) The social amplification of risk: A conceptual framework. *Risk analysis* 8 177-187.
- Kasperson, R. E. and J. X. Kasperson (1996). "The social amplification and attenuation of risk." *The Annals of the American Academy of Political and Social Science* 545: 95-105.
- Kitzinger, J (1999) *A Sociology of Media Power: Key Issues in Audience Reception Research*. In: G Philo (ed) *Message Received: Glasgow Media Group Research 1993-1998*. London. Longman, pp 3-20.
- Kloprogge, P.; van der Sluijs, J. and Wardekker, A. (2007) *Uncertainty communication issues and good practice*. University of Utrecht Report NWS-E-2007-199.
- Krauss, M.P.K. von, Kaiser, M.; Almaas, V.; van der Sluijs, J.; Kloprogge, P. (2004) Diagnosing and prioritizing uncertainties according to their relevance for policy: The case of transgene silencing *Science Direct* 2007.
- Krupnick, A.; Morgenstern, R.; Batz, M.; Nelson, P.; Burtraw, D.; Shih, J.S. and McWilliams, M. (2006) *Not a sure thing: Marking regulatory choices under uncertainty*. Washington DC: Resources for the future.
- Kuhn, T.S.(1972) *The Structure of Scientific Revolutions*.
- Kunreuther, H. Gupta, S. et al, (2010) *Integrated Risk and Uncertainty Assessment of Climate Change Response Policies*. IPCC 2010 http://www.ipcc.ch/pdf/assessment-report/ar5/wg3/ipcc_wg3_ar5_chapter2.pdf
- Levin, R. (2006). Adequacy Conditions for Reporting Uncertainty in Chemical Risk Assessments *Human and Ecological Risk Assessment: An International Journal*, 12(5), 834-855
- Lichtenstein, S.; Slovic, P.; Fischhoff, P.; Layman, M. & Coombs, N, (1978) Judged frequency of lethal actions. *Journal of experimental psychology* 4; 551-578.
- Lipkus M. and Hollands, J,G, (1999) The visual communication of risk. *Journal of the national cancer research institute*, 25; 149-162

- Lowenstein, G. and Elster, J. (eds) (1992) *Choice over time*, New York: Russell Sage.
- Frederick, S.; Loewenstein, G. & O'Donoghue, T. (2002) Time Discounting and Time Preference A critical review. *Journal of Economic Literature* June; 351-401.
- MacFarland, C. and Miller, D.T. (1994) The framing of relative performance feedback: Seeing the glass as half empty or half full. *Journal of Personality and Social Psychology*, 66(6); 1061-1073.
- Marris, C., Langford, I. & O'Riordan, T. (1996) A comparison and integration of the psychometric and cultural theory approaches to risk perceptions. *Journal of Risk Analysis* 17(3); 303-310.
- Marris, C. (2001) Public views on GMOs: deconstructing the myths. *EMBO reports*, 21(7), 545-548.
- Marx, S.M.; Weber, E.U.; Orlove, B.S.; Leiserowitz, A.; Krantz, D.H.; Roncoli, C; and Phillips, J. (2007) Communication and mental processes: Experimental and analytic processing of uncertain climate information.
- Mazur, A. (1984) "Media Influences on Public Attitudes Toward Nuclear Power," in W. R. Freudenburg and E. A. Rosa (eds.), *Public Reactions to Nuclear Power: Are There Critical Masses?* (American Association for the Advancement of Science/Westview, Boulder, CO), pp. 97-114.
- Mazur, A. and J. Lee (1993). "Sounding the global alarm - environmental-issues in the united-states national news." *Social Studies Of Science* 23: 681-720.
- McCombs, M. E. and D. L. Shaw (1972). The agenda-setting function of mass media *Public Opinion Quarterly* 36(2): 176-187
- McKenna, F. P; R. A. Stanier; C. Lewis (1991). Factors underlying illusory self-assessment of driving skill in males and females. *Accident Analysis and Prevention* 23: 45-52.
- McKenna, F. (1993) It won't happen to me. Unrealistic optimism and the illusion of control. *British Journal of Psychology*, 84; 39-50.
- McLeod, A. (2010) The EPPO pest risk analysis scheme: comments on using risk scales. *OEPP/EPPO Bulletin* 40: 1310138.
- McNair, S., M. Flynn, L. Owen, C. Humphreys and S. Woodfield (2004) *Changing Work in Later Life: A Study of Job Transitions*, Centre for Research into the Older Workforce, University of Surrey, Guildford.
- Miles, S. and L. J. Frewer (2003). "Public perception of scientific uncertainty in relation to food hazards." *Journal of Risk Research* 6(3): 267-283.
- Millar, A., Simeone, R.S., & Carnevale, J.T. (2001). Logic models: A systems tool for performance management. *Evaluation and Program Planning*, 24, 73-81.
- Miller, D. and Reilly, J. (1995). 'Making an Issue of Food Safety: The Media, Pressure Groups and the Public Sphere', in D. Maurer and J. Sobal (eds.), *Eating Agendas: Food and Nutrition as Social Problems*. New York: Aldine de Gruyter
- Millner, A.; Calel, R.; Stainforth, D. and MacKerron, G. (2010) Do probabilistic expert elicitation capture scientists' uncertainty about climate change? *Climatic Change Letters* manuscript.

http://cats.lse.ac.uk/homevss/david2/publications/MillnerEtAl_ClimaticChange_2012_FinalManuscript.pdf

- Morgan, M.G.; Fischhoff, B.; Bostrom, A.; Lave, L. and Attman, C.J. (1992) Communicating risk to the public. First learn what people know. *Environmental Science and Technology* 26: 2048-2056.
- Morgan, M.G. and Henrion, M. (1990) *Uncertainty a guide to dealing with uncertainty in quantitative risk and policy analysis*. Cambridge University Press.
- Morgan, M.G. (2010) Quantitative expert subjective judgement: does it have a role in future IPCC assessments? IPCC Workshop, 2010.
- Morgan, M.G. and Herrion, M (1990) *Uncertainty, a guide to dealing with uncertainty in quantitative risk and policy analysis*. Cambridge University Press.
- Morgan, M.G.; Fischhoff, B.; Bostron, A.; and Atman, J. (2001) *Risk Communication A Mental Models Approach*. Cambridge, UK.
- Morgan, M. G. (2014). "Our Knowledge of the World is Often Not Simple: Policymakers Should Not Duck that Fact, But Should Deal with It." *Risk Analysis* 35(1): 19-20.
- Moss, R.H. and Schneider, S.H. (1997) Characterizing and Communicating Scientific Uncertainty: Building on the IPCC Second Assessment. In *Elements of Change 1996*, S.J. Hassol and J. Katzenberger, eds. (Aspen, CO: Aspen Global Change Institute), 90-135.
- Murdock, G., et al. (2003). After amplification: rethinking the role of the media in risk communication. In Eds: N. Pidgeon, R. Kasperson and P. Slovic, *The social amplification of risk..* Cambridge, Cambridge University Press: 156-178.
- Murphy, A.H. *et al* (1980), "Misinterpretations of precipitation probability forecasts," *Bulletin of the American Meteorological Society*, 61, 695-701.
- Mussweiler, T. and Strack, F. (1998) Hypothesis-Consistent Testing and Semantic Priming in the Anchoring Paradigm: A Selective Accessibility Model. *Journal of Experimental Social Psychology*. 35, 136-164.
- National Research Council (1989). *Improving risk communication*, National Academies Press
- Nelkin, D. (1991). "Aids and the news media." *Milbank Quarterly* 69: 293-307
- O'Brien, M. (2000). Have lessons been learned from the UK bovine spongiform encephalopathy (BSE) epidemic? *International Journal of Epidemiology*, 29(4), 730-733
- Oppenheim, A.N. (1966) *Questionnaire design and attitude measurement*. London: Heinemann.
- O'Hara, R.; Johnson, M.; Hirst, E.; Weyman, A.; Shaw, D.; Mortimer. P.; Newman. C.; Storey. M.; Turner, J. and Mason, S. (2014) A qualitative study of decision making in ambulance service transition. National Institute for Health Research. Health services delivery research 2(56)56 December DOI 10.3310/hsdr02560
- Otway, H.J. & von Winterfeldt, D. (1992). Expert judgement in risk analysis and management: Process, context, and pitfalls. *Risk Analysis*, 12; 83-93.

- Parry, G.W. (1996) The characterisation of uncertainty in probabilistic risk assessment of complex systems. *Reliab. Eng. Syst. Staf.* 54' 119-126.
- Pepper, S., & Prytulak, L. S. (1974). Sometimes frequently means seldom: Context effects in the interpretation of quantitative expressions. *Journal of Research in Personality*, 8, 95-101.
- Peters, E., & Slovic, P. (1996). The role of affect and worldviews as orienting dispositions in the perception and acceptance of nuclear power. *Journal of Applied Social Psychology*, 26, 1427–1453.
- Petts, J. I., et al. (2001). *Social Amplification of Risk: the Media and the Public*, Contract Research Report 329/2001. Sudbury., HSE Books.
- Pidgeon, N. (1996) Risk perception, trust and stakeholder values. Framing the risk communications question. Cited in: HM Inspectorate of Pollution Proceedings of Risk Perception and Communications Seminar. Dept of Environment Report DOE/HMIP/RR/95.011.
- Pidgeon, N.; Walls, J., Weyman, A. and Horlick-Jones, T. (2003) Perceptions of and trust in the Health and Safety Executive as a risk regulator. Health and Safety Executive Research Report 100.
- Pidgeon N. and Barnett, J, (2013) Chalara and the Social Amplification of Risk. Department for Environment and Rural Affairs.
https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/200394/pb13909-chalara-social-amplification-risk.pdf
- Power, M. (2006) The risk management of everything. Demos.
- Rabinovich, A. and T. A. Morton (2012). "Unquestioned Answers or Unanswered Questions: Beliefs about Science Guide Responses to Uncertainty in Climate Change Risk Communication." *Risk Analysis* 32(6): 992-1002
- Reason, James (1997). *Managing the risks of organizational accidents*. Aldershot: Ashgate.
- Rowe, W. D. (1994) Understanding Uncertainty *Risk Analysis*, 14(5), 743-750
- Pratt, A.G. and Dessai, S. (2005) Communicating uncertainty - lessons learned and suggestions for climate change assessment . *C.R. Geoscience* 337; 425-441.
- Patt A,G, and Schlagg, D.P. (2003) Using specific language to describe describe risk and probability. *Climate change*. 61; 17-30.
- Ross, L. (1977). The intuitive psychologist and his shortcomings: Distortions in the attribution process. In L. Berkowitz (Ed.), *Advances in experimental social psychology* (vol. 10). New York: Academic Press.
- Royal Society (1992) Risk Perception. Royal Society group on risk assessment, analysis, perception and management. Pidgeon N.; Hood, C.; Jones, D.; Turner, B. & Gibson, R. Royal Society London.
- Rowe, G. (2010) Assessment of the COT uncertainty framework from a social science perspective: A theoretical evaluation. Report to the Food Standards Agency.
- Rawlinson, S. (2004) *Construction Safety Management Systems*. Spon Pres, London.

- Sia, C. L., Tan, B., & Wei, K. K. (2002). Group Polarization and Computer-Mediated Communication: Effects of Communication Cues, Social Presence, and Anonymity. *Information Systems Research*, 13, 70–90.
- Schachter, S. (1951). Deviation, Rejection, and communication. *Journal of Abnormal and Social Psychology*, 46, 190-208.
- Shepperd, James; Malone, Wendi, Sweeny, Kate (2008) Exploring Causes of the Self-serving Bias. *Social and Personality Psychology Compass* 2 (2): 895–908
- Simon, Herbert (1957). "A Behavioral Model of Rational Choice", in *Models of Man, Social and Rational: Mathematical Essays on Rational Human Behavior in a Social Setting*. New York: Wiley.
- Simon, H. (1996a) *Models of my life*. MIT Edition Cambridge MA; MIT Press.
- Simmons, J.P.; Leboeuf, R.A.; Nelson, L.D. (2010) The Effect of Accuracy Motivation on Anchoring and Adjustment: Do People Adjust From Provided Anchors? *Journal of Personality and Social Psychology*. 99(6) 917–932.
- Sjoberg, L (1967) Successive intervals scaling of paired comparisons. *Psychometrika* 32(3).
- Slottje, P.; Sluijs, J.P. van der and Knol, A.B. (2008) Expert elicitation: methodological suggestions for its use in environmental health impact assessment. RIVM Letter report 630004001.
- Slovic, P. (1987) Perception of risk. *Science*, 236(4799), 280-285
- Slovic, P., Fischhoff, B., Lichtenstein, S. (1982) Why Study Risk Perception? *Risk Analysis* 2(2): 83–93.
- Slovic, P.; Flynn, J.; & Gregory, R. (1994) Stigma happens. Societal problems in the sighting of nuclear waste facilities. *Risk Analysis* 14(5); 773-777.
- Slovic, P. (1995). The construction of preference. *American Psychologist*, 50, 364-371.
- Solesbury, W. (2001) *Evidence Based Policy: Whence it Came and Where it's Going?* ESRC UK Centre for Evidence Based Policy and Practice Queen Mary University of London. <https://www.kcl.ac.uk/sspp/departments/politiceconomy/research/cep/pubs/papers/assets/wp1.pdf>
- Stirling, A. (2010). Keep it complex. *Nature* 468(7327): 1029-1031
- Strack, F. & Mussweiler, T. (1997) Explaining the enigmatic anchoring effect. Mechanisms of selective accessibility. *Attitudes and Social Cognition*. 73(3), 467-446.
- Thaler, T. and Sunstein, C. (2008) *Nudge*. Yale University Press.
- Thurstone, L.L. (1927) A law of comparative judgements. *Psychological Review* 34. 273-286.
- Thurstone, L. L. (1959) *The measurement of values*. University of Chicago Press.
- Tree Health and Plant Biosecurity Expert Taskforce (2013) Final report, <https://www.gov.uk/government/publications/tree-health-and-plant-biosecurity-expert-taskforce-final-report>
- Tversky, A. and Kahneman, D. (1971) Belief in the law of small numbers. *Psychology Bulletin* 76. 105-110.

- Tversky, A. and Kahneman, D (1973) Availability: a heuristic for judging frequency and probability. *Cognitive psychology*: 207-232
- Tversky, A. and Kahneman, D. (1974) Judgement under uncertainty, heuristics and biases, *Science* 185, 211; 453-458
- Tversky, A. and Kahneman, D. (1992) Advances in prospect theory: Cumulative representation of uncertainty. *Journal of Risk and Uncertainty*. 5(4); 297-323
- Turner, M. E., & Pratkanis, A. R. (1998). Twenty-five years of groupthink theory and research: Lessons from the evaluation of a theory. *Organizational Behavior & Human Decision Processes*, 73(2-3), 105-115.
- Turner, S.; Keeley, D.; Glossop, M.; Brownless, G. (2002) Review of Railway Safety's Safety Risk Model. Health and Safety Laboratory HSL/2002/06
- Turner, S. (2004) A methodology for the assignment of safety integrity levels (SILs) to safety-related control functions implemented by safety-related electrical, electronic and programmable electronic control systems of machines. Health & Safety Executive Research Report 216.
- U.S. Nuclear Regulatory Commission (2008) Effective Risk Communication (NUREG/BR-0308) The Nuclear Regulatory Commission's Guideline for External Risk Communication. <http://www.nrc.gov/reading-rm/doc-collections/nuregs/brochures/br0308/>
- van der Sluijs, J.P, Janssen, P.H.M.; Petersen, A.C.; Kloprogge, P.; Risbey, J.S.; Tuinstra, W. and Ravetz, J.R. NUSAP (2000) RIVM/MNP Guidance for Uncertainty Assessment and Communication: Tool Catalogue for Uncertainty Assessment. Report nr: NWS-E-2004-37
- Van der Sluijs, J.P.; Petersen, A.C.; Janssen, P.H.M.; Rishey, J.S. and Ravety. J.R. (2008) Exploring the quality of evidence for complex and contested policy decisions. *Environmental research letters*. IOP Publishing, UK.
- Viscusi, W.K., Magat, & Huber (1991) Communication of ambiguous risk information. *Theory and Decision*, 31(159), 173
- Visser, H.; Petersen, A.C.; Beusen, A.H.W.; Heuberger, P.S.C. and Janssen. P.H.M. (2006) Guidance for uncertainty assessment and communication. Check-list for uncertainty in spatial information and visualising spatial uncertainty. Netherlands Environment Assessment Agency. Project S/550032/01/LO
- Waage, J.K. and Mumford, J.D. (2008). Agricultural biosecurity. *Philosophical transactions of the Royal Society Biological Sciences*. 863-876
- Wahlberg, A. and L. Sjoberg (2000). "Risk perception and the media." *Journal of Risk Research* 3(1): 31-50
- Wallsten, T. S., & Budescu, D. V. (1995). A review of human linguistic probability processing: General principles and empirical evidence. *The Knowledge Engineering Review*, 10(01), 43-62
- Wallsten, T.S.; Budescu, D.V.; Rapoport, A.; Zwick, R.; & Forsyth, B. (1986) Measuring the vague meanings of probability terms. *Journal of Experimental Psychology*, 115(4); 348-365.

- Wardekker, J.A. and van der Sluijs, J.P. (2005) Report of the expert meeting uncertainty communication. Utrecht 10 Dec. Utrecht University, Department of Science, Technology and Society.
- Wardekker, J.A.; van der Sluijs, J.P.; Janssen, P.H.M.; Kloprogge, P. and Petersen, A.C. (2008) Uncertainty communication in environmental assessment views from the Dutch science-policy interface. *Environmental Science and Policy* 11; 627-641.
- Wardekker, J.A. de Jong, A.; van Bree, L.; Turkenburg, W.C. van der Sluijs, J.P. (2012) Health risks of climate change. An assessment of uncertainties and its implications for adaptation policies. *Environmental Health* 11, 67.
- Weinberg, A. (1972) Science and Trans-Science. *Minerva* 10(2): 209-222. (1974)
- Weinstein, N.D. (1980) Unrealistic optimism about future life events. *Journal of Personality and Social Psychology* 39; 906-920.
- Weinstein, N.D. (1984) Why it won't happen to me. Perceptions of risk factors and susceptibility. *Health Psychology* 3 ; 431-457.
- Weinstein, N.D. (1993) Testing four competing theories of health-protective behaviour, *Health Psychology*, 12(4): 324-33
- Weyman, AK; Pittard, VP; Goddard, H & Riley, DB (1995) Pilot investigation into asbestos risk awareness amongst building maintenance workers' Health and Safety Executive Report No: IR/L/EBS/95/2. March.
- Weyman and Anderson, (1998) Assessment of the application of risk assessment in the UK mining industry. HSE Report No: IR/L/EWP/95/9
- Weyman A.K. and Kelly, C.J. (1999) Risk Communication a review of literature. Health and Safety Executive Research Report 248.
- Weyman, A.K. and Clarke, D.D. (2003) 'Investigating the Influence of Organisational Role on Perceptions of Risk in Deep Coal Mines' *Journal of Applied Psychology*, June.
- Weyman A.K.; Chambers, H.; & Keen, C. (2004)- 'Occupational exposure limits - Mental models in risk control'. *Annals of Occupational Hygiene*, March.
- Weyman A.K & Bibby, P. (2005) Development of a public perception of risk gauging tool. Report to Risk Policy Unit Health and Safety Executive, unpublished.
- Weyman, A.K. & Williamson, J. (2007) Veterinary Medicines, Gauging Public Concern – Health and Safety Laboratory Report to the Food Standards Agency, August 2007.
- White, W.H. (1956) *The organisational man*. New York. Simon and Schuster.
- Whyte, G (1989) Groupthink reconsidered. *Academy of Management Review* 14(1); 40-56.
- Windschitl, P.D. and Weber, E. (1999) The interpretation of 'likely' depends on the context but 70% is 70% - right? The influence of associative processes on perceived certainty. *Journal of Experimental Psychology: Learning, Memory and Cognition*. 25(6); 1514-1533.
- Wynne, B. (1989) Frameworks of rationality in risk management. Towards a history of naive sociology. in: J. Braun (Ed) *Environmental threats*. London, Bellhaven Press.

- Wynne, B. (1992) Misunderstood misunderstanding. Social identities and public uptake of science. *Public understanding of Science*; 281-304.
- Wynne, B. (1992). Uncertainty and environmental learning: Reconceiving science and policy in the preventive paradigm. *Global Environmental Change*, 2(2), 111-127
- Wynne, B. (1989). "Sheepfarming after Chernobyl: A Case Study in Communicating Scientific Information." *Environment* 31(2): 10-39
- Yamagishi, K/ (1997) When a 12.86% mortality is more dangerous than 24.14%: implications for risk communication. *Applied Cognitive Psychology* 11(6) 495-506.
- Yousuf, M.I. (2007) Using Experts' Opinions Through Delphi Technique. *Practical assessment, research and evaluation*. 12(4).
- Zwik, R. (1989) Combining stochastic uncertainty and linguistic inexactness: theory and experimental evaluation of four fuzzy probability models. *International Journal of Man-Machine Studies* 30; 69-111.
- Zimmer, A. (1984) A model for the interpretation of verbal predictions. *International Journal of Man-Machine Studies*, 20; 121-134